Three Essays on Competition and Innovation

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Abstract

Information and communication technologies (ICT) are driving the modern innovation process. To better understand these dynamics, the current dissertation analyses the interactions between innovation and competition. The scope of this work can be divided into two areas: The first one deals with a question of how markets could be organized to produce the most optimal outcome. The second one analyses the feedback effects of innovative activity on competition and the organisation of economic activity.

Regarding the impact of competition on innovation, an empirical analysis reveals that ICT- driven innovations dominate in concentrated industries, whereas innovations based on other technologies flourish in moderately competitive markets. This suggests that there are some features that make ICT-enabled innovations exceptional, compared to innovations based on other technologies. Concerning the impact of innovation on competition, two findings are worth emphasising. First, as shown in a theoretical analysis, although profitable from an individual producer's perspective, the adoption of a technology increasing product variety across the entire industry erodes firms' payoffs. In addition, firms' decisions with respect to the technology adoption are not always efficient from the social welfare point of view. Second, another empirical analysis included in this work reveals that ICT leads to more competition and facilitates the emergence of hybrid organization forms, subject to firm's and industry's characteristics.

Although this dissertation reveals only a small piece of the complexity of the ICT-driven innovation process, it casts some new light on the importance of market structure for ICT- enabled innovation and the feedback effect of the technology on firms' environment. Interestingly, the outcomes of this thesis show that these interactions are often far from straightforward and in many cases counterintuitive.

Key words: Competition, innovation, market structure, organisational forms, Information and Communication Technologies, ICT

Zusammenfassung

Informations- und Kommunikationstechnologien (IKT) sind der Antrieb des modernen Innovationsprozesses. Für besseres Verständnis dieser Dynamik, analysiert diese Dissertation die Wechselwirkungen zwischen Innovation und Wettbewerb. Die Arbeit umfasst zwei Teile: Erstens wird die Frage behandelt, wie die Märkte organisiert werden können, um das optimale Marktergebnis zu erreichen. Zweitens werden die Rückwirkungen der innovativen Tätigkeit auf Wettbewerb und auf Organisation der wirtschaftlichen Tätigkeit analysiert.

Betrachtet man den Einfluss von Wettbewerb auf Innovation, zeigt eine empirische Analyse, dass IKT-getriebene Innovationen in konzentrierten Industrien vorherrschen. Im Gegensatz dazu gedeihen Innovationen, die auf anderen Technologien basieren, in eher vollkommenen Märkten. Der Vergleich suggeriert, dass die IKT-getriebene Innovationen andere Charakteristika aufweisen als Innovationen, die auf anderen Technologien basieren. Betrachtet man die Rückwirkung von Innovation auf Wettbewerb, sind zwei Ergebnisse wert genannt zu werden. Erstens, obwohl profitabel von der Perspektive einzelner Unternehmen aus, sinkt der Industrieprofit, wenn eine produktvielfaltsteigernde Technologie durch alle Firmen übernommen wird. Des Weiteren sind die Entscheidungen der Unternehmen in Bezug auf die Technologieadoption nicht immer optimal aus Sicht der sozialen Wohlstandsmaximierung. Zweitens in Bezug auf Organisation der wirtschaftlichen Tätigkeit wird gezeigt, dass IKT sowohl zu mehr Wettbewerb als auch zu der Entstehung von hybriden Organisationsformen führen kann, was von den jeweiligen Charakteristika der Unternehmen abhängt.

Obwohl diese Dissertation nur ein kleines Stück der Komplexität analysiert, wirft sie ein neues Licht auf die Zusammenhänge von Marktesstruktur und Innovation und ihre gegenseitigen Rückwirkungen. Interessanterweise sind die Ergebnisse weit entfernt von gewohnten Sichtweisen und in vielen Fällen entgegen der intuitiven Ausgangserwartung.

Schlagwörter: Wettbewerb, Innovation, Markstruktur, Organisationsformen, Informations- und Kommunikationstechnologien, IKT

Dedication

To my family.

Contents

Chapter 1

Introduction

1.1 Purpose

It is beyond dispute that technological progress stands behind the rapid evolution of the industrial economies and their economic growth. Modern societies recognize innovative activity and technological development as a key element of creating and sustaining their well-being. Today, however, the capability to innovate becomes more important than ever as it is seen not only as a means to sustain welfare but, ironically, as a solution to the problems resulting from the rapid growth as well. Thus, the question of what are the most optimal conditions for generating optimal economic outcome receives currently considerable amount of attention from economists, policy makers and the business world alike. For the same reasons we are interested in how innovation and technological progress change the environment in which they take place.

Following the Schumpeterian concept of creative destruction, this thesis analyses the interdependencies between economic conditions and innovative activity that has been driven over the last decades by the diffusion of information and communication technologies (ICT). The research presented in the following chapters can be divided into two areas. The first area belongs to the most studied in the field of the industrial organization and includes such research question as how firms and markets should be organized to produce the most optimal economic and social outcome. The main issue of interest concerns the relationship between competition and innovation. The second area arises from the first one and concentrates on providing an answer to the question of how innovative activity changes the economic conditions. In particular, what is the feedback effect of ICT-enabled innovations on post-innovation competition?

Although the interactions between economic environment and innovation have been a subject of intensive research, Schumpeter (1942) was first to spell out the problem of the possible trade-off between static and dynamic efficiency. He claimed that desirable market performance could not be attained in static competition among producers of existing products whose main role is to adjust prices and quantities. In his view, only actual or potential competition of new products or new producers employing novel production methods drives economic growth. Furthermore, according to Schumpeter, innovating firms need to use some monopolistic practices that deter imitation and enable them to reap profits from their investments in innovative activities. He argued that large firms with monopoly power are apt to innovate and, therefore, their presence benefits the society in the long term. In other words, monopolies and market power can be justified and sometimes even desired. For example, monopolistic profits are necessary to secure funds for further research. The benefits accruing to the society from the new products or improved production techniques will eventually balance off any welfare loss. This concept of creative destruction, popularized in economics by Schumpeter, is based on the assumption that the equilibrium state is being distorted by entrepreneurs who introduce innovations. A successful innovation replaces existing technologies and changes the economic conditions as well as the position of incumbent firms. The ultimate remedy to the negative effects of incumbent's monopoly power would be competition coming from entrants.

By introducing ideas formulated by evolutionary biologists to the field of economies, Schumpeter did not only challenge the antitrust orthodoxy but inspired an intensive debate on the process of technological change and its consequences. His works became the foundation of evolutionary economics and endogenous growth theory (Nelson and Nelson (2002)). Evolutionary economics is based on the idea that market competition functions in a similar way to biological competition. Firms must pass a survival test whose conditions are imposed by the market (Nelson and Winter (1982)). Although similarly to neoclassical economics, evolutionary economics uses a different approach when analysing the interdependencies between competition, technological development, institutions and resource constraints. Whereas neoclassical economics models maximization problems of rational individuals, evolutionary economics is concerned with developing a framework to understand the process of economic change, which is primarily driven by changes in technology. In a similar way, endogenous growth theory drops the assumption that the economic growth is exogenously determined and treats the development of new technologies and the accumulation of knowledge as central to economic growth (Aghion and Howitt (1998)).

In the following, I explain the main aspects of this thesis and its contributions to understanding the inter-relationships between competition and innovation. Then, I give a short overview of the remaining parts of this work.

1.2 Contributions

This thesis takes the process of the diffusion of ICT as an ongoing example of creative destruction at work and acknowledges the fact that there is a two-way interaction between technology and economic life. On the one hand, the adoption and diffusion of ICT can be spurred by many drivers and can have far reaching consequences, on the other hand (Breshnahan and Trajtenberg (1995), Helpman (1998)). Virtually all economic spheres can be affected by ICT-induced changes, including innovation dynamics, productivity and growth, the development of market structures, and the composition of labour demand. These powerful effects of ICT result from the fact that ICT is recognized as “general purpose technology” (GPT) (Bresnahan and Trajtenberg (1996), Jovanovic and Rousseau (2005)). GPT is a term describing a new method of producing and inventing that has an extensive impact on a wide range of economic activities. Examples of other GPT include steam, electricity, and internal combustion. Just as other GPTs, ICT enhances productivity and improves firm performance by enabling the development of new products, cheaper production of existing goods, process re-organization and organizational change (Brynjolfsson and Hitt (2000)).

Due to the fact that there is little evidence on the interdependencies between ICT-spurred technological change and economic environment, this thesis provides some new facts on these interactions and helps to understand how competition affects and is affected by the ICT-induced innovative process. Regarding the results of the following analyses, a number of novel results can be pointed out:

First, in the analysis of the relationship between competition and innovative activity in chapter 2, I find that ICT-driven innovations dominate in concentrated markets, whereas their non-ICT counterparts seem to flourish in moderately competitive markets. However, these relationships become weaker once industry effects are included. That leads to the conclusion that innovative activity is not necessarily determined by either market power or its lack, but instead depends on more subtle characteristics of a firm and the industry in which it operates and, of course, the technological conditions. There are a number of features that make ICT-enabled innovations exceptional, compared to other innovations. First, they are derived from a disruptive technology (Teece (1986)). Second, they are heavy dependent on information and knowledge, which typically increases fixed cost of innovating (Carlton and Gertner (2003)). Additional features characteristic to most of ICT-enabled innovations include the dependency on network effects, critical mass and switching cost. Although these attributes are often cited to be particularly important for software and computer hardware products or telecommunication services, they are not limited to these products only. Considerable dependency on information, network effects, and switching costs can be observed for other ICT-enabled innovations such as virtual networks that link firms in a value chain or new products and services invented in the internet era (Bresnahan and Greenstein (2001), Economides (2003)). Thus, the uniqueness of ICT-induced innovations can give a hint as to why this type of innovations dominates in concentrated markets. Because all these make them very capital- and knowledge-intensive, ICT-enabled innovations are primarily present in industries in which firms have some market power.

Second, chapter 3 includes a theoretical analysis of the impact of new technology on competition and the organization of economic activities in supply chain. To my best knowledge, this is the first attempt to formalize the introduction of a technology that enables firms to extend their product portfolio in the vertical context. This analysis shows that, although profitable from an individual producer's perspective, the adoption of technologies increasing product variety across the entire industry erodes firms' payoffs. In particular, when products are close substitutes, any benefits stemming from an increased product variety do not justify investments into flexible technology by all firms in the industry. The strategic interactions between firms in the industry lead to excessive investments and, consequently, make firms worse off. As a result, producers end up in a Prisoners' Dilemma.

Third, the results of the analysis presented in chapter 4 reveal that ICT is a technology that enables firms to reduce cost and, in a strategic perspective, to stimulate the level of competition between their business partners. This explains the prevailing move to the market as a means of organizing economic activity. However, despite the technological superiority of ICT networks and the resulting lower transaction cost, companies' behaviour with respect to the sourcing strategy is still not homogeneous. It seems that firm's structural characteristics play a significant part in what effect ICT has on their choice of sourcing options. Consequently, on the one hand, ICT leads to more competition, and facilitates the emergence of hybrid organization forms that are based on cooperation and competition, on the other hand.

Regarding the empirical side, there are a few methodological techniques employed in this work, which are worth mentioning. For example, to analyse the relationship between competition and innovation, two approaches were taken. First, I used semi-parametric spline regressions, which allowed me to drop the linearity assumption and to get an insight into the shape of the relationship between the two variables. Second, having obtained evidence supporting the hypothesis that market competition does not have a homogeneous effect on different types of innovations, a number of empirical tests were run in accordance to the Bayesian inference principles. This approach allows for a high degree of flexibility and at the same time guarantees that the results remain robust.

The quality of the empirical analyses was considerably improved by the use of representative large-scale enterprise survey data that was collected by the e-Business Watch project, an initiative launched and sponsored by the European Commission. This is a unique dataset that contains very detailed and rich information on individual firms' technology and innovative activity in a number of European industries. Furthermore, to study the relationship between competition and innovation, the e-Business Watch data was merged with selected indicators from the EU KLEMS dataset.

In conclusion, the results of this thesis illustrate the interactions between competition, the technology adoption and the resulting innovations. Although this work reveals only a small piece of the complexity of the inter-dependencies between market structure and firms' behaviour, it casts some new light on the importance of market structure in the innovative process and the feedback effect of the technology on firms' environment. Interestingly, the outcomes of this thesis show that these interactions are often far from straightforward and in many cases counterintuitive.

1.3 Outline

Besides the introductory chapter, this thesis consists of three chapters. Despite the fact that this work is based on three independent essays, it has a common element that links all of them together. This is the inter-dependency between competition, ICT as a general purpose technology and innovation.

Chapter 2 deals with the relationship between competition and innovation. Although there is already a lot of literature that aims to identify which market structure is most conducive to innovation (Kamien and Schwartz (1982), Cohen and Levin (1989)), there is still a lack of agreement regarding this issue. Thus, Cohen and Levin (1989) point out that the research objectives should be refocused from the narrowly defined relations to the fundamental sources of technological change. Similarly, despite his life-long experience in studying the dependency between market structure and innovation, Scherer (2006) concludes that the most favourable environment for technological progress depends upon nuanced circumstances. Thus, the motivation behind the analysis in chapter 2 is to account for the heterogeneity of the innovative process and market conditions. The main question of this analysis is whether there is a relationship between competition and innovation at all and, if yes, whether it varies with the type of innovation or the technology from which an innovation is derived. In order to answer the above questions, I make use of four direct measures of innovative: non-ICT- and ICT-enabled product innovations and non-ICT- and ICT-enabled process innovations. The analysis is based on two data sources. The first one, e-Business Watch, provides data on firms' innovative activity. The second one, EU KLEMS, is a source of competition measure. On the empirical side, I apply Bayesian inference techniques.

Chapter 3 includes a theoretical analysis of the interplay between the value chain organization, the adoption of flexible production technologies (FPT) leading to more product variety and welfare implications of such actions. In order to link the characteristics of FPT with the firm scope and supplier relations, I develop a model that allows for an analysis of suppliers' incentives to merge and manufacturers' decisions regarding the choice of production technologies that are specific to inputs produced by suppliers. Choosing FPT over dedicated production technology (DPT) allows a manufacturer to gain access to inputs necessary to extend its product variety. Two questions are of major importance here: First, how does the structure of the upstream industry, market size and the degree of product differentiation affect producers' incentives to adopt FPT? Second, what are the welfare implications of the decisions regarding investments in the production technologies under different structures of the upstream industry?

Chapter 4 presents an econometric analysis of the impact of ICT-enabled procurement networks on the choice of the number of sourcing options. Electronic procurement as an ICT-enabled innovation has been one of the main reasons why the character of the supplier-buyer relations has been going through dramatic changes over the last decades (Skjott-Larsen et al. (2003)). However, because there are many channels through which electronic procurement affects the value chain interactions, there is little evidence as to what are the implications of the introduction of this technology on supplier-buyer relations and the existing works offer only an incomplete picture. Thus, this analysis acknowledges that although the main benefits of electronic procurement include the reduction in labour and material costs, sourcing cycle times and inventory levels (Presutti (2003)), its strategic feature is to support the use of market mechanisms and to induce price competition among suppliers (Lancioni et al. (2003)). In order to investigate how electronic procurement changes companies' sourcing behaviour, I conduct an econometric analysis based on the e-Business Watch 2006 survey data.

Chapter 2

Competition and ICT- and non-ICT innovations

2.1 Introduction

Innovation can pay large dividends for society. As a result, the determinants of innovative activity have received much attention not only from economists but also from policy makers and business people. However, although the problem of the identification of the industry structure that offers greatest incentives for innovation has been one of the mostly discussed topics in the field of industrial organization, so far there is no consensus on how competition or its lack affects companies' innovative activity (Gilbert (2006)). The reason for this are different settings and assumptions of the theoretical models that aim at explaining the relationship between competition and innovation. Thus, in this analysis we take a different approach. Instead of looking for the most optimal type of market structure for innovative activity we tackle the question of how market competition affects different types of innovations.

An important element of our analysis is that we take into account the contradicting predictions of theoretical models with respect to competition and firms' innovative behavior (e.g. Schmutzler (2007)). Rather than selecting one type of theoretical model and testing its validity, we acknowledge that most of the models have clear predictions and that they differ with respect to the assumptions made. To allow for such flexibility, we make use of data and an empirical method that take into account the nature of the existing theories. The analysis is based on a unique data set compiling data on innovative activity and a competition measure at the sectoral level for a number of European countries. Our data has two significant advantages. First, it includes the following four direct measures of innovative: non-ICT- and ICT-enabled product innovations and non-ICT- and ICT-enabled process innovations. Thus, in contrast to a large bulk of literature, we use innovation measures that depict real product and process innovations conducted by firms instead of proxies such as R&D expenditures or the number of patents typically used. Furthermore, our measures of innovative output allow us to control for the heterogeneity of innovation output. Due to the fact that the data used in this analysis provides information on whether an innovation conducted by a firm was based on information and communication technology (ICT) or not, we can identify the type of technology that was used in the innovation process. In other words, given the general purpose character of ICT (Bresnahan and Trajtenberg (1996)), we are able to make a distinction between the original technology that an innovation was derived from. Second, our competition variable is based on the concept of economic rents, rather than concentration ratio or market share indicators. Its main advantage over other commonly used indicators is that it does not require the observation of the firm's complete market in order to describe competition. This is particularly important considering that a large share of companies operate in international markets, which poses considerable limitations on other competition measures. Regarding the empirical methodology, we apply Bayesian inference techniques. The most important reason for the choice of Bayesian method is that it enables us to account for the different predictions of the available theory and, consequently, different solutions. By reporting posterior distributions of model parameters, we can subsequently make statements regarding the probability and, consequently, the validity of each theoretical prediction, instead of rejecting any of the competing hypothesis. Furthermore, Bayesian method is less sensitive to the problems regarding small sample size.

As mentioned above, the main motivation of this analysis was to conduct a comprehensive study that would acknowledge the fact that the relationship between competition and innovation is a multifaceted one (Scherer and Ross (1990)). This diversity is reflected in the abundance of theoretical models that deliver contradicting predictions. The source of these inconclusive claims are the differences related to the assumptions made with respect to the competition type and technological characteristics. The very first analysis of market structure and incentives to innovate was conducted by Arrow (1964). Contradicting Schumpeter (Schumpeter (1942)), he formally advanced the claim that a newcomer may have greater incentives to innovate than a monopolistic firm. Arrow's conclusions were, however, revised by subsequent works. For example, the way of thinking about competition and innovation was strongly influenced by Salop (1977) and Dixit and Stiglitz (1977) who argued that intense market competition reduces the incentives to innovate. Similar, Segerstrom and Zolnierek (1999) show that industry leading firms with significant market shares undertake most of the industry innovative activities. A more recent work by Aghion et al. (2005) shows that there is no simple answer to the question of what is the most optimal market structure for the dynamic efficiency. According to the authors, the final effect of competition on innovation depends on the net effect of competition on the pre- and post-innovative profits of firms active in the industry. An interesting overview of a number of theoretical settings and their implications for the relationship between competition and innovation is presented by Schmutzler (2007). He shows that the effects of increasing competition on innovation investments can be positive, negative or non-monotone. In his explanation, he identifies four different transmission channels by which competition affects investments and argues that the number of interactions is a source of ambiguous effects of competition on innovation. Consequently, it is not possible to formulate a universal model that could explain this relationship.

The results of the empirical analysis match the ambiguity of the results of the theoretical works. The studies on the relationship between competition and innovation was pioneered by Frederic M. Scherer. In one of his studies, Scherer (1965) expressed his disapproval of the idea of monopoly being an apt market structure for technological progress. He concluded that innovative output does not seem to exhibit any positive correlation with market power or even with profitability before a successful innovation. Later on, however, Scherer (1967) found that the innovative output tended to increase with the market concentration level. Explaining the discrepancies between both studies, he adhered to the complexity of the relationship and the need to account for inter-industry differences such as technological opportunity. Eventually, he advanced an argument of a threshold, up to which higher industry concentration level promotes innovation competition. The hypothesis of a U-shaped curve, reflecting relations between market power and innovative activity, was partially supported by Comanor (1967) as well. However, he argued that monopoly power may cause higher research efforts only in industries in which product differentiation possibilities are limited and that this relationship does not exist in sectors in which innovation competition plays an important role. Further studies showed little, if any, causality effect between increasing market power and innovation. In a more recent study, Geroski (1994) provided strong support against the concept that monopoly power has a positive and direct effect on innovation. According to him, incomplete treatment of the technological opportunity has lead to biased results of the previous studies. In particular, it seems that the usual methodology of testing the Schumpeterian hypothesis contains a flaw which imparts a distinctly 'pro-Schumpeterian' bias to the results. The study showed that industries with high technological opportunity are characterized by a high concentration ratio, considerable market size, and higher profitability. Mansfield recapitulated the results of empirical research in the following words: "*[a] slight amount of concentration may promote more rapid invention and innovation (. . .). But beyond a moderate amount of concentration, further increases in concentration do not seem to be associated with more rapid rates of technological advance(...)*"(see Baldwin and Scott, 1987, p. 90). Again, reconciling conclusion can be found in Aghion et al. (2005) who show that there is an inverted U-shape relationship between competition and innovation.

Due to the lack of agreement, Cohen and Levin (1989) pointed out that the research objectives should be refocused from the narrowly defined relationships to the fundamental sources of technological change. Consequently, over the recent decades economists have gradually dispensed with the notions of complete information, profit maximization and predictability (Aghion and Howitt (1995)). Accounting for uncertainty and bounded rationality, the evolutionary approach to economic phenomena has been suggested. According to Gort and Klepper (1982) and Klepper (1996), the innovation process changes together with industry evolution. For example, at the beginning of the industry formation, entrants account for a disproportionate share of product innovations. The diversity of competing versions of the product and the number of major product innovations tend to reach a peak during the growth in the number of producers and then fall. Over time, producers devote increasing effort to process relative to product innovation. Towards the end of an industry life cycle, the advantage of size increases firm's process innovation incentives and efforts.

Similar implications for the innovation process as the industry life cycle has the technological change. For example, in a case study based analysis of innovation patterns in a variety of industries, Christensen (1997) shows that industry leaders often reject important inventions and fail to bring them to the market. Entrepreneurial companies are more likely to exploit these opportunities. What at first sight looks surprising is easy to explain. According to Arend (1999), entrants and incumbents make rational decisions to invest in radical innovations or not. The most obvious reason why incumbents choose not to pursue radical innovations is the fact that at the beginning the market for them is nonexistent or rather small, which makes such investments unattractive or unprofitable for the incumbent firm. Another argument says that the incumbent's incentives to compete with an entrant for a new opportunity are rather low (Reinganum (1983)). This arises due to the cannibalization of its current profits. Incumbents prefer to use the available technology rather than the future one and, consequently, devote resources to the current profits rather to the future ones. Entrants, in contrast, focus on tomorrow's opportunities and choose to compete in the future using future technology.

Considering the interrelations between market evolution, technological change and the process of innovation, it becomes obvious that any analysis studying the relationship between competition and innovation should take into account at least two issues. First, there is a quantitative difference between product and process innovations. Therefore, one can expect that the intensity of each type of innovative activity might vary with competition. Second, technologies evolve and are replaced over the industry life-cycle. Consequently, the relationship between competition, technological shift and the resulting change in the innovative process might be of different nature as compared to a static state.

An example of a technological shift and a transformation of the innovative process is the spread of ICT commonly recognized as a general purpose technology (GPT). GPT is a term describing a new method of producing and inventing that has an extensive impact on a wide range of economic activities (Jovanovic and Rousseau (2005)). Similar to such GPTs as electricity or steam engine, the diffusion of ICT enhances productivity and improves firm performance by enabling development of new products, cheaper production of existing goods, process re-organization and organizational change (e.g. Brynjolfsson and Hitt (2000); Bharadwaj (2000); Köllinger; Nepelski (2009); Venkatraman (1991)). Thus, the ICT-driven technological change moves firms towards a new technological trajectory. In view of the above discussion, it is necessary to ask whether the effect of market competition on innovation changes with the type of innovation.

The scope of innovative activity covered in this study distinguishes it from others that tackle the relationship between innovation and competition. In particular, the inclusion of ICT-enabled innovations makes it absolutely unique. Thus, it is necessary to explain the character and importance of such innovations. According to the literature on user adoption of innovation in ICT, these type of innovations are not primarily cost reducing (Bresnahan and Greenstein (2001)). The use of ICT primarily enables improvements in the quality and the reliability of products and services (Brynjolfsson and Hitt (1996)). Furthermore, novel ICT applications frequently lead to the introduction of entirely new services and products. Regarding ICT-enabled process innovations, this is mainly a result of adopting software, which embeds business processes and organizational structures. Thus, the adoption and business use of ICT applications reinforces the process of process innovation and organizational redesign (Hammer and Champy (1995)).

Our analysis provides evidence that supports the hypothesis that the effect of market competition on innovation is not alike for all types of innovation. First, we observe an inverse U-shape relationship between competition and non-ICT-enabled innovations. Second, a clear U-shape dependency can be observed for ICT-enabled innovations. However, once industry effects are included in the analysis, the results become considerably weaker. Thus, to some extent, we provide evidence that is consistent with the seemingly contradictory predictions of various models and confirm the findings stating that the effect between competition and innovation is only of minor importance. As already indicated in previous studies, other factors seem to have a stronger impact on the innovative activity. Consequently, any implications for innovation policy and further research in this area should take into account the type of innovations, the maturity of the industry and the life cycle of the technology.

The remaining of the chapter is organized as follows. Section 2.2 presents the data used and describes the process of data matching. Section 2.3 discusses the methodology. Section 2.4 presents the results and Section 2.5 concludes.

2.2 Data sources and data matching

In our analysis we use two data sources to obtain information on innovation activity and competition level at the industry level. The first is the e-Business Watch project and provides measures of innovation activity. The second is the database developed within the EU KLEMS research project and is a source of competition measures.

e-Business Watch is an initiative launched by the European Commission in 2001 with the aim to monitor the adoption, development and impact of electronic business practices in different sectors of the European economy (see: www.ebusiness-watch.org). The enterprise surveys conducted within the e-Business Watch project focused on the availability and usage of ICT and the perceived importance and impact of e-business at the company level. Apart from the numerous questions relating to the usage and relevance of ICT, all data sets contain background information about each firm, e.g. sector, country of origin, number of employees, size class and number of establishments. Since 2003, the respondents were asked about their companies' innovative activities. Thus, in this work, we use data from the 2003, 2005 and 2006 surveys. The total number of observations in all three data sets exceeds 26,600 enterprises. Annex gives a detailed description of the surveys and the data sets used in this study together with an overview of sectors and countries covered by each individual survey.

EU KLEMS is a research project that analyzes productivity developments in the European Union at the industry level (see www.euklems.net). One of its product is a database including measures of economic growth, productivity, employment creation, capital formation and technological change at the industry level. The database uses a 63-industry breakdown in accordance to the NACE classification code for the major of the EU's 25 Member States as well as for the US, Japan and Canada, from 1970 onwards. The input measures include various categories of capital, labour, energy, material and service inputs. In addition, the data set includes several measures of knowledge creation. The information on value added and labour compensation enables us to construct a competition measure at the industry level.

In order to match the data from both sources, we followed the sector-country classification of the e-Business Watch and defined our markets accordingly. Then, we matched each observation unit from the e-Business Watch data set with its counterpart in the EU KLEMS data set. Following this matching procedure, we obtained observations which can be defined as single markets, whereas each market is one industry in one country. We included only sectors that can be characterized as ICT-users and excluded industries producing ICT equipment and services, such as the ICT manufacturing or ICT services industries, both covered by the 2006 survey. The justification for this was the fact that it is difficult to draw a line between non-ICT- and ICT-enabled innovations in sectors whose primary products are ICT-based, e.g. equipment, services or software.

Due to the fact that sectors covered by the e-Business Watch surveys were very narrowly defined, in many cases it was not possible to find its counterpart in the EU KLEMS data set. Therefore, if that was the case, the sector was excluded from the final analysis. Similarly, some observations were dropped because of a limited number of countries covered in the EU KLEMS data set. Eventually, we obtained a sample of 260 individual markets across the European economy, out of 363 potential observations originally included in the e-Business Watch database. The final data set includes complete information on innovative activity and competition level. Table 2.1 shows the final list of sectors included in the analysis together with the NACE classification codes in both data sets.

Table 2.1: Mapping datasets

e-Business Watch		EU KLEMS NACE Code
Sector definition	NACE Code	
Survey 2003		
Business services	74	74
Chemical industries	24, 25	24, 25
Crafts and trade	20, 36	20, 36
Electronics	30, 31, 32	30, 31, 32
Hospital activities	85	N
Retail	52	52
Textile industries	17, 18.1, 18.2, 19.3	17, 18
Tourism	55, 62, 63, 70, 92	H, 63, 92
Transport equipment	34, 35	34, 35
Survey 2005		
Automotive industry	34	34
Construction	45	F
Food and beverages	15	15
Machinery and equipment	29	29
Pharmaceutical industry	24.4, 24.5	24.4
Publishing and printing	22	22
Textile industry	17, 18	17, 18
Tourism	55, [62], 63, 92	H, 63, 92
Survey 2006		
Consumer electronics	32	32
Construction	45	F
Food and beverages	15	15
Footwear	19	19
Hospital activities	85	N
Pulp, paper and paper products	21	21
Shipbuilding and repair	35.1	35.1
Telecommunication services	64	64
Tourism	55, 63, 92	H, 63, 92

2.2.1 Measuring innovation

There exists no measure of innovation that permits readily interpretable cross-industry comparisons (e.g. Cohen and Levin (1989)). Moreover, the value of innovation is difficult to assess, particularly when the innovation is embodied in consumer products (Griliches (1979)). In order to overcome the shortcomings of traditionally applied measures of innovative activity, we make use of direct measures of innovations. In the e-Business Watch surveys, each respondent was asked a question of whether her company had introduced substantially improved products or services to its customers during the past 12 months prior to the date of the interview. Similarly, survey participants were also asked if the company had introduced new internal processes during the past 12 months. To allow for a comparison with similar research projects, the questions regarding a firm's innovative activities were adopted from the Community Innovation Survey (CIS 2004) to determine the share of companies that recently introduced product or process innovations. In addition to the introductory questions on innovation, the interest was also on the share of innovative activity that is directly related to or enabled by information and communication technology. Therefore, companies that indicated in the introductory questions that they have conducted innovations in the past 12 months were asked follow up questions. Consequently, we are able to distinguish between the following four types of innovations:

- Non-ICT-enabled product innovations,
- ICT-enabled product innovations,
- Non-ICT-enabled process innovations,
- ICT-enabled process innovations.

Because this study is at a sector level, we had to aggregate companie's answers to the questions of interest. Therefore, in order to compute innovation rates for each sector-country cell, we first summed up companies' positive answers to the questions regarding their innovation activity and divided by the number of all firms in the relevant sector-country cell. The final innovation measures are indices for each type of innovation that can take any value between 0 and 1. If the value of an index is 0, none of the companies belonging to a certain market covered by the survey has conducted any of the relevant innovation. In contrast, if an index takes value of 1, it means that all companies in the market have introduced a particular type of innovation.

As in other studies, our measures suffer from some limitations. First, we need to rely on respondents' perceptions. Second, we are not able to quantify the value of different innovations. Nevertheless, compared to commonly used innovations measures, such as the number of patents or R&D spending, the most obvious advantage of our innovations indicators is the fact that we use a direct measure of innovative activity that is related to the innovative output. Furthermore, we are able to control for the heterogeneity of innovation type. The latter is decisive for obtaining a consistent picture of the relationship between competition and firms' innovative activity type, which is a distinct feature of this study.

2.2.2 Measuring competition

The measurement of profits and consequently market competition at the macroeconomic level is subject to a high degree of uncertainty and may also reflect measurement problems associated with other economic variables. Empirical studies analyzing the relationship between competition and innovation are marked by considerable deficiencies in capturing the level of competition (Cohen and Levin (1989)). The most important problem of these studies was the choice of an appropriate indicator of market level competition and finding empirical data that could allow for an extensive study of the issue. Thus, the measure of competition applied in this study is based on the concept of economic rents, rather than concentration ratio or market share indicators. One problem with applying a measure of economic rents as a proxy for market power is that a high gross margin is a natural feature of dynamic, innovation-driven industries and its mere existence is not a basis to conclude that there is monopolization (Geroski (1994)). Despite this limitation, a measure of market competition based on economic rents has some straightforward advantages over other indicators, such as market shares or Herfindal index, commonly used in studies of competition and innovation. Computing economic rents does not require the observation of the firm's complete market in order to describe competition. This is particularly important considering that a large share of companies operate in international markets. In such cases, traditional market competition measures quickly reach their limitations. Thus, as in Aghion et al. (2005), the Lerner index is very attractive as a measure of market competition. However, given that the direct empirical measurement of the Lerner index is quite difficult since firms' marginal costs are not observable, we make use of gross margin as a proxy of market competition. The gross margin is defined as the ratio of sales minus cost of goods sold to sales (Gitman (1994)).

In order to create a proxy for a gross margin at the industry level by using the EU KLEMS data, we define our measure of competition as the difference between value added and labour compensation as a proportion of value added, i.e.:

$$GM_{ij} = \frac{VA_{ij} - LC_{ij}}{VA_{ij}}, \tag{2.1}$$

where LC_{ij} is the labour compensation and VA_{ij} is total value added of industry j in country i. Examples of using the concept of gross margin as a measure of competition include Cowley, P.R. (1985), Holdren (1965), Livingston and Levitt (1959) and Nevo (2001) and a similar approach to the measurement of competition by using macroeconomic data can be found in Crespi and Patel (2007) and ECB (2006). To make the interpretation of the following analysis more intuitive, we use

$$c_{ij} = 1 - GM_{ij}, \tag{2.2}$$

where c_{ij} stands for competition level in country i and industry j. The values of c_{ij} can range between 0 and 1 and it can be interpreted in a reverse way to the Lerner index. As c_{ij} increases, so does the competition level.

In order to reduce the problem of endogeneity, we lagged the data on competition by two periods relatively to the observation on innovation. Thus, as companies were asked about innovation activity in the last 12 months before the survey, the information on competition level comes from at least a year before any innovation took place. For example, the data from the 2003 survey was matched with the EU KLEMS data from 2001.

2.3 Method

2.3.1 Empirical model

The main question of the current analysis is what kind of relationship exists between innovation and competition, i.e. what is the shape of $g(c_{ij})$? In contrast to previous studies discussed above, we make a qualitative distinction between different types of innovation. Thus, for each type of innovative activity we model innovation intensity in country i and industry j in the following way:

$$I_{kij} = \alpha + g(c_{ij}) + \beta x_j + \varepsilon_{ij} \tag{2.3}$$

where I_{kij} denotes innovation rate of innovation type $k = 1, ..., 4$, i.e. non-ICT-enabled and ICT-enabled product and process innovations, α is a constant and x_j is a complete set of industry dummy variables. Following other studies (e.g. Aghion (2005)), we refrain from imposing any particular form of $g(c_{ij})$. Instead, we allow for a flexible functional form of the dependency between innovation and competition. In the proceeding section we make use of visual data analysis techniques, which will allow us to identify the shape of $g(c_{ij})$.

An important concern regarding the model specified above is the problem of endogeneity (see, for example, Nepelski, 2003). It is a well known fact that there is a two-way causality effect between market structure or market power and innovation. In other words, just as competition influences the intensity of innovative behavior, innovation influences market competition. Thus, in order to minimize the endogeneity problem, data on competition was lagged by two periods, relatively to the data on innovation.

A number of studies shows that once additional variables are introduced the effect of competition on innovation activity diminishes or disappears completely (see, for example, Geroski (1994)). Thus, in order to account for other factors that might have an influence not only on the innovation intensity but also on the type of innovations, we control for industry effects by including sector dummies in one of the specifications.

2.3.2 Bayesian method

The literature survey presented above reveals that the economic theory of innovation and competition is very inconclusive and, depending on the assumptions, leads to different conclusions. Thus, instead of asking what is the optimal level of competition for innovative output, our analysis focuses on how the impact of competition on innovation changes subject to the type of innovation. The main purpose of this analysis is to operationalize and validate the existing pieces of seemingly contradicting hypotheses in order to obtain a consistent picture of the relationship between competition and innovative activity.

A logical step in reexamining this issue is the choice of an appropriate empirical method, which can take into account the nature of the existing theories. It is evident that the difference in theoretical conclusions stems from the assumptions made with respect to the characteristics of innovation or technology used. Thus, an appropriate method should allow for a study of innovation and technological phenomena, as they can determine the impact of competition on innovative activity. However, most of the empirical studies in this area use some variations of regression analysis estimated by using traditional statistical techniques (for a literature overview see, for example, Kamien and Schwartz (1982) or Baldwin and Scott (1987)). The major focus of these studies is to test whether there is a relationship between competition and innovation measured by an aggregated measure such as R&D expenditures or the number of patents. Consequently, the results of these studies indicate only that, on average, competition negatively or positively affects the studied measure of innovation and they do not allow to make any comment with respect to a specific probability that such a relationship exists for a particular type of innovation. In order to fill this gap, we propose Bayesian inference.

The principles of Bayesian interference

The Bayesian approach is characterized by the use of external information sources, which is called *prior* information. This information is usually captured in terms of probability distribution based on previous studies or historical information. Despite its convenience of use and intuitive presentation of results, Bayesian methods have become widely used only in the last two decades. Until recently, mainly due to computational requirements, there were only few classes of models for which the posterior could be computed. Furthermore, many researchers disputed the quality of an approach in which *subjective* prior information is used. To tackle this problem and to increase the robustness of the results, most of the analyses include various assumptions regarding the priors.

In addition, the widespread use of such simulation methods as Markov Chain Monte Carlo (MCMC) eliminated most of the computational obstacles for a number of models and reduced the concern of the influence of the prior on the coefficient estimates. In particular, the possibility of conducting a large number of simulations considerably reduced the influence of priors on the final results. As a result, Bayesian methods have been intensively used in a number of disciplines. Some examples from the economics studies in which Bayesian inference techniques were used are Fryar, Arnold and Dunn (1988) and Mountain and Illman (1995). Applications in other disciplines, such as management, include, among others, Hansen et al. (2004), Block and Thams (2007). Furthermore, an overview of studies in marketing, in which Bayesian techniques were used, can be found in Rossi et al. (2003).

All Bayesian methods rely on Bayes' theorem of probability theory (Lancaster, (2004)), which can be expressed as

$$\Pr(\theta \mid y) = \frac{\Pr(y \mid \theta) \Pr(\theta)}{\Pr(y)}, \tag{2.4}$$

where θ represents the set of unknown parameters, and y represents the observed data. $\Pr(\theta)$ is the prior distribution of the unknown parameters. $\Pr(y \mid \theta)$ is the likelihood function, which is the probability of the data y given θ. $\Pr(y)$ is the marginal distribution of the data, and $\Pr(\theta \mid y)$ represents the posterior distribution, which is the probability of the parameter θ given the data y.

When testing a hypothesized relationship between two variables, Bayesian analysis proceeds in the following steps. First, a priori beliefs about the relationship of interest, i.e. $\Pr(\theta)$, are formulated. Next, a probability of occurrence of the data given these beliefs, i.e. $\Pr(y \mid \theta)$, is assumed. In the second step, data is used to update these beliefs. The result is the posterior distribution, i.e. $\Pr(\theta \mid y)$, of all parameters included in the model specification. Thus, Bayesian inference allows for statements in terms of *likely* and *unlikely* parameter values or effects on the dependent variable.

In practice, Bayesian probability statements regarding the parameters conditional on the data are often interpreted in a similar way to classical confidence statements about the probability of random intervals covering the true parameter value. This is however not correct (Sims (1988); Sims and Uhling (1991)). According to the frequentists approach, a population mean is not known, but can be estimated from a sample. Thus, by knowing or assuming the distribution of the sample mean, confidence interval is constructed that is centred at the sample mean. Then, the only statement that can be made is that 95% or 90%, accuracy level depends on arbitrary preferences, of similar intervals would contain the population mean, if each interval was constructed from random samples. In contrast, the Bayesian approach proceeds by constructing a credible interval that is centered around the sample mean. Eventually, by using the Bayesian approach, one can state that there is, for example, 95% or 90% probability that this interval contains the mean.

Another implication of Bayesian econometrics is that it is less concerned with the sampling issue, compared to the frequentist approach. Instead, Bayesian econometrics rely on the data at hand. This brings the focus of the analysis to more fundamental questions like, for example, what is the relation between the available data and the model or how to deal with the discrepancies between the empirical results and what the theory suggests?

These characteristics of Bayesian inference have some clear advantages for our analysis. First, we do not assume that there are any true and fixed coefficients, which allows us to account for the differences in the dependency of innovative activity on competition. This is useful because the theory describing the relationship between competition and innovation is far from being consistent and includes competing hypotheses. Bayesian analysis states the probability or the extent to what a particular hypotheses can be confirmed by the observations. Consequently, it allows us to determine which hypothesis describes our data with a higher probability, instead of rejecting any hypotheses as being not relevant at all.

Bayesian calculations and Marcov chain Monte Carlo simulation

As mentioned above, one of the main reasons for the late take-off of the Bayesian techniques use was the computational difficulty. The joint posterior distribution, i.e. $\Pr(\theta \mid y)$, is in many situation hundred- or thousand-fold dimensional, which makes it very complex and unavailable in closed form (Lunn et al. (2000)). As it is shown in the next section, Bayesian inference involves the estimation of various summary statistics of the posterior distributions, such as mean, standard deviation or quantiles. In order to obtain these measures, one needs to integrate functions that involve $(\theta \mid y)$ with respect to θ, which considerably limits the use of Bayesian method. MCMC simulation allows one to overcome this problem, i.e. it substitutes for multi-dimensional integration as a means to parameter estimation (e.g. Chib and Greenberg (1996) and Kloek and van Dijk (1978)).

In Bayesian interference, MCMC simulation methods are used to evaluate integrals from a Marcov chain that is constructed in a way that its stationary distribution is the posterior. For that purpose, there are two commonly used simulation algorithms: Gibbs and Metropolis sampler (Lancaster (2004)). Both algorithms proceeds by iterative simulation from the full conditional distributions of each unknown stochastic quantities taking into account the current values of all other terms of the model. The Gibbs sampler is implemented in the WinBUGS algorithm (Lunn et al. (2000)), which was used to conduct computation included in the current analysis.

2.4 Empirical analysis

2.4.1 Descriptive statistics

Table 2.2 shows mean values of innovation rates for each type of innovation activity and competition levels broken down by sectors. Regarding process innovation, 14% of all process innovations were not ICT-enabled and only 24% were in some way driven by ICT. Such discrepancy does not exist in the case of product innovations. There are however significant variations in the type of innovation activity between industries. For example, whereas in the telecommunication sector nearly one half of all product innovations were enabled by ICT, in the construction or pharmaceutical sectors such innovations accounted for only around 10% of all product innovations. Similar patterns can be observed for process innovations. Furthermore, the large value of standard deviations and the discrepancies between minimal and maximum values of all innovation measures indicate that there are considerable differences between the markets (see table 2.8, Annex). To some extent, this can be explained by the discrepancies in the use of ICT across sectors. At the same time, however, this is also a reflection of differences in the demand for various types of technologies that firms use and technological regimes they operate in. This indicates also to what extent new technologies, such as ICT, can be used in different sectors to introduce new products or improve production processes.

Regarding competition levels, it can be seen that, on average, the telecommunication and chemical industries are the least competitive. On the other extreme, the hospital activities and shipbuilding sectors exhibit the highest

Table 2.2: Descriptive statistics

Sector	Non-ICT-enabled innovations		ICT-enabled innovations		Competition
	product	process	product	process	
Automotive industry	0.35	0.19	0.15	0.28	0.63
Business services	0.25	0.24	0.23	0.21	0.57
Chemical industries	0.16	0.18	0.46	0.28	0.45
Construction	0.12	0.09	0.11	0.19	0.54
Consumer electronics	0.18	0.10	0.31	0.23	0.61
Crafts and trade	0.06	0.05	0.31	0.13	0.53
Electronics	0.24	0.22	0.30	0.26	0.58
Food and beverages	0.38	0.16	0.11	0.23	0.55
Hospital activities	0.15	0.18	0.31	0.27	0.77
Machinery and equipment	0.34	0.17	0.15	0.24	0.71
Pharmaceutical industry	0.52	0.20	0.11	0.30	0.54
Publishing and printing	0.18	0.10	0.26	0.41	0.62
Pulp, paper and paper products	0.22	0.12	0.15	0.23	0.54
Retail	0.23	0.26	0.39	0.19	0.48
Shipbuilding and repair	0.14	0.15	0.12	0.11	0.88
Telecommunication services	0.09	0.03	0.46	0.42	0.39
Textile industries	0.25	0.13	0.21	0.19	0.69
Tourism	0.20	0.13	0.20	0.23	0.52
Transport equipment	0.15	0.16	0.35	0.25	0.56
Total	0.22	0.14	0.23	0.24	0.57

levels of competition within the studied sample. A closer look at the detailed statistics reveals that the competition level strongly varies in our sample (see table 2.8, Annex). Although the mean and median values are slightly higher than 0.5, the minimum and maximum values, $c = 0.11$ and $c = 0.97$ respectively, indicate that our sample includes both types of markets, i.e. nearly monopolies and perfectly competitive markets.

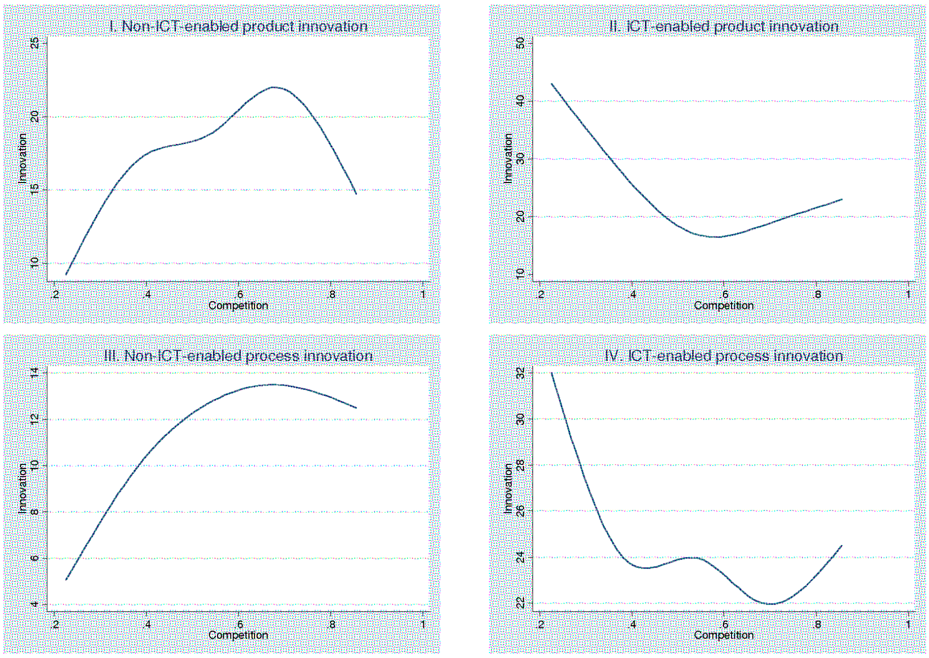
Some insights into the relationship between competition and innovation activity delivers the analysis of the correlation coefficients (see table 2.9, Annex).Whereas there is a positive, though not significant, correlation between competition and both non-ICT-enabled innovation types, the reverse is true for ICT-enabled innovations. Both types of ICT-enabled innovations are negatively correlated with the competition measure. Taking all these facts together, it can be assumed that an increasing market competition decreases firms' propensity to adopt ICT tools and, as a result, to use ICT in their innovation process. Considering the potential problem of multicollinearity, the values of correaltion cofficients are relatively moderate. This indicates that the analysis does not suffer from serious multicollinearity problem.

2.4.2 Univariate analysis

Before proceeding with a regression analysis, we start with exploring the relationship between competition and all four types of innovations in a univariate analysis by inspecting a series of data plots. For each type of innovation we illustrate the dependency between competition and innovation rate by fitting a median spline function. A median spline function is a semiparametric method that aims at fitting a function that matches the relationship between the dependent and independent variables (Smith (1979)). This is done in two steps. First, the independent variable is split into equally spaced intervals. As the results of alternative set ups were qualitatively not different, in the following we present the case where the number of intervals is equal to 5. Second, cross medians are calculated and used as knots to fit a cubic spline. The resulting spline is graphed as a line plot. By using such a method, we can get a first insight into the shape of the function describing the dependency between competition and all four innovation types.

Figure 2.1 shows the results of spline estimations. The shape of these curves indicates that there is a considerable heterogeneity across different types of innovation with respect to competition. On the one hand, we can observe a positive relation between non-ICT-enabled innovation. Although far from an inverted U shape, the lines indicate that the propensity to conduct both product and process non-ICT-enabled innovations increases at a decreasing rate with the competition level. This reminds of the results obtained in some of the previous studies (see for example Scherer (1967) and Aghion et al. (2005)). On the other hand, however, when analyzing ICT-enabled innovations, it is clear to see that there is a negative relationship between innovative activity and competition. For both types of innovation, the highest rate of innovative activity can be observed in the least competitive markets. Then, as competition increases, the innovative activity decreases at an increasing rate to reach its minimum between .5 and .7 and to increase slightly in the region of the highest competition.

Figure 2.1: Innovation and competition, semiparametric estimation (median splines)



Similar to Aghion et al. (2005), we can conclude that the relationship between innovation and competition is not linear. However, once we can control for the type of innovation, it becomes evident that for some types of innovation, non-ICT-enabled ones, the function is concave and for others, ICT-enabled ones, it is convex. Because we do not control for other factors that might influence firms' innovative behavior, the above results are only approximations of the possible relationships between different types of innovation and competition. Thus, we now proceed to a more thorough analysis in which we estimate a number of models in which we control for other factors that might influence the innovative process. Furthermore, by including additional variables, we want to test the strength of the relations established above.

2.4.3 Bayesian estimations

Taking into account the results of the spline analysis (figure 2.1), we start the examination of the relationship between competition and various types of innovation by estimating three models. First, we start with a basic model in which function $g(c_{ij})$ is linear. In order to focus only on the dependency between the two variables of interest, we do not include sector dummies. Thus, the first equation to be estimated can be expressed by

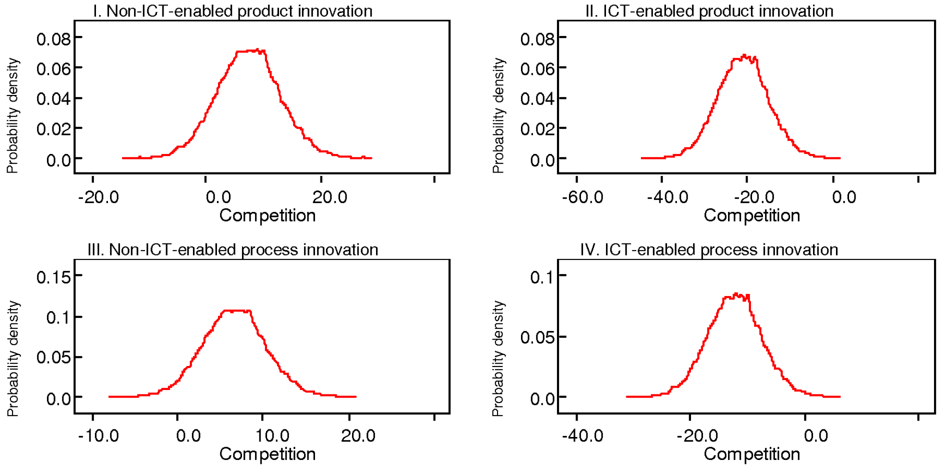
$$I_{kij} = \alpha + \beta_1 c_{ij} + \varepsilon_{ij} \tag{2.5}$$

where I_{kij} denotes innovation rate of innovation type, $k = 1, ..., 4$, α is a constant, c_{ij} is our measure of competition and ε_{ij} represents an error term. In the second model, following the observation in the previous section (figure 2.1), we relax the assumption that there is a linear relationship between competition and innovative activity. Consequently, in the next analysis, we want to estimate a model in which $g(c_{ij})$ takes a quadratic form, i.e. $g(c_{ij}) = \beta_1 c_{ij} + \beta_2 c_{ij}^2$. Our last specification goes beyond examining the relationship between competition and innovation and includes sector effects as well.

All priors for the model parameters carry little information, i.e. they are assumed to be normally distributed with $\mu = 0$ and $\tau = 0.001$. In other words, in order not to influence the results by assumptions on priors, we state that there is no relationship between the dependent and independent variables. The motivation behind using such a conservative approach are varying theoretical predictions with respect to the relationship between our two variables and the first results of the spline analysis. Such prior specification ensures that we eliminate the bias towards any of the hypotheses. The initial state of *no dependency* is further validated in the regression. Any deviation from the initial assumptions can be interpreted as evidence for the presence of some dependency between the variables of interest.

To estimate the three models, all computations were done by using MCMC simulation method. The number of draws was set at 11,000 and the first 1,000

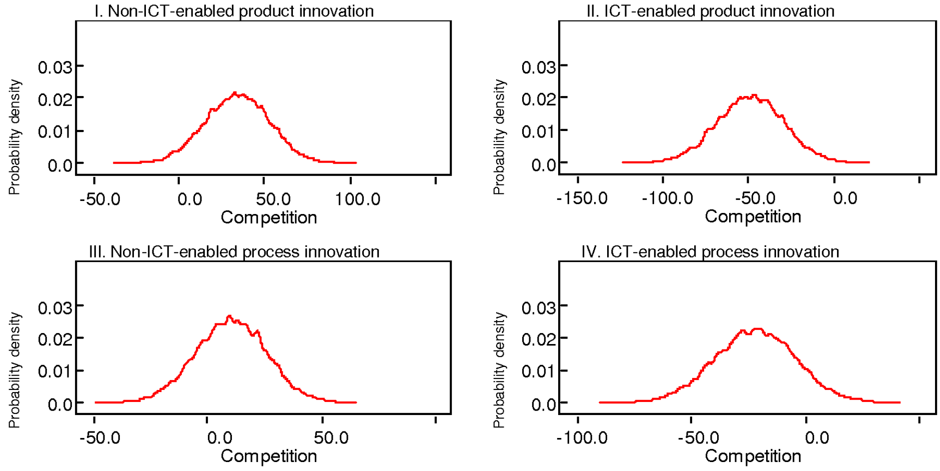
Figure 2.2: The effect of competition on innovation: Basic specification, Bayesian estimation



draws were discarded.

One of the main advantages of the Bayesian estimation is that it provides information about the posterior distributions of each model parameter, which contains more information than a single metric reported by traditional techniques. These distributions can be of course presented in a graphical way, making the interpretation of the results even more intuitive. Figure 2.2 shows posterior distributions of competition variable estimated for the basic model for each type of innovation. Regarding non-ICT-enabled product innovations, over 90% of the surface of the distribution function lies to the right from zero. This represents the probability of a positive effect of competition on this particular type of innovations. The remaining part of the curve, to the left from zero, shows the probability of competition having a negative effect on non-ICT-enabled product innovations. In other words, there is over 90% probability that competition has a positive effect on non-ICT-enabled product innovations. A similar conclusion can be made with respect to non-ICT-enabled process innovations. Turning to ICT-enabled innovations, however, it can be seen that a reverse pattern can be observed. Both posterior distribution curves lie to the left from zero, which suggests that there is a negative relationship between competition and innovations derived from ICT. These results are consistent with the outcomes of the univariate analysis in previous section.

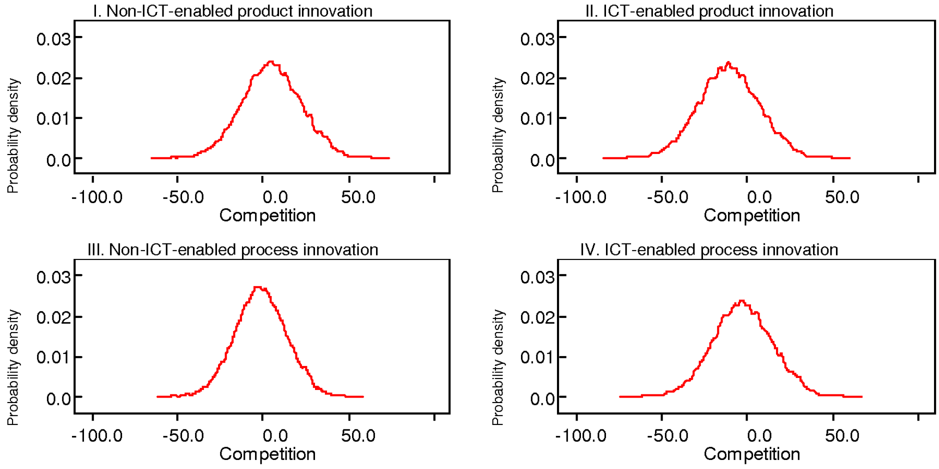
Figure 2.3: The effect of competition on innovation by innovation type: Qadratic specification, Bayesian estimation



Along graphical presentation, the results of Bayesian estimation can be presented in a conventional way by using metrics as well. Table 2.3 presents the distributions of posteriors for each parameter across the three models. For each posterior distribution, five quantiles of the probability density functions are reported, i.e. 5%, 25%, 50%, 75% and 95%. Regarding the basic estimation, it can be seen that the probability that competition positively influences the likelihood of introducing non-ICT-enabled product innovation case is over 0.9. In contrast, the opposite can be said about ICT-enabled product innovations. There, it can be seen that there it is certain that increasing competition has a negative implication for the intensity of ICT-enabled product innovations. Regarding process innovations, we can again see the same pattern as above. Whereas there is a large probability of a positive impact of competition on non-ICT-enabled innovations, the opposite effect can be observed for ICT-enabled ones.

Regarding the second specification, in which $g(c_{ij}) = \beta_1 c_{ij} + \beta_2 c_{ij}^2$, it can be seen that despite some changes in the coefficient values, there are no strong qualitative deviations from the previous observations (see figure

Figure 2.4: The effect of competition on innovation by innovation type: Qadratic specification with industry effects, Bayesian estimation



2.3 and table 2.3, second column). In particular, the results for both types of product innovations remain unchanged and we can still observe a clear negative (positive) impact of competition on (non)-ICT-enabled innovations. There is, however, a small difference in the way the competition coefficient reacts to the inclusion of the quadratic term. Whereas, the duality of the impact of competition on product innovations becomes even more polarized, its effect on process innovations becomes less heterogeneous than before. Regarding the coefficient values of the quadratic term, consistently with the previous observation reported in figure 2.1, we can observe that the rate of non-ICT-enabled innovations increases at a decreasing rate and that the reverse holds for ICT-enabled innovations.

Turning to the results of the last specification, the posterior distribution curves are shown in figure 2.4 and the values of the median and individual quantiles in the last column of table 2.3. It can be seen that the impact of competition on any type of innovative activity becomes considerably weaker once we include industry effects. In particular, in contrast to product innovations, the discrepancy in the impact of competition on different types of process innovations diminishes. The shape of the density curves of the competition variable suggests that the areas indicating positive and negative

Table 2.3: Competition and innovation; Bayesian estimations

	Non-ICT-enabled product innovations														
	Basic estimation					Quadratic estimation					Quadratic estimation with industry effects				
Quantiles	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%
Constant	11.91	15.14	17.27	19.44	22.54	1.75	6.95	10.66	14.48	19.77	9.761	14.66	18.16	21.55	26.48
Competition	-1.47	3.78	7.48	11.07	16.65	3.00	21.36	34.24	46.96	64.34	-23.08	-6.458	4.91	16.53	34.01
Competition²						-51.65	-36.03	-24.82	-13.61	3.12	-33.71	-18.21	-7.37	3.09	18.38
Industry effects													Yes		
	Non-ICT-enabled process innovations														
Quantiles	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%
Constant	6.24	8.39	9.80	11.24	13.30	1.73	5.89	8.85	11.88	16.10	5.95	10.16	13.13	15.99	20.15
Competition	0.71	4.19	6.65	9.03	12.74	-15.33	-0.04	10.43	20.98	35.29	-25.69	-11.28	-1.44	8.76	24.04
Competition²						-25.38	-12.61	-3.51	5.75	19.38	-23.77	-10.25	-0.88	8.25	21.44
Industry effects													Yes		
	ICT-enabled product innovations														
Quantiles	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%
Constant	28.82	32.28	34.56	36.90	40.22	32.04	37.61	41.46	45.43	50.84	18.55	23.59	27.22	30.70	35.82
Competition	-30.55	-24.97	-20.98	-17.14	-11.18	-81.00	-61.81	-48.63	-35.69	-17.09	-39.60	-22.52	-10.82	1.28	19.31
Competition²						-2.04	14.13	25.74	37.40	54.41	-26.95	-10.97	0.22	10.94	26.65
Industry effects													Yes		
	ICT-enabled process innovations														
Quantiles	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%
Constant	26.46	29.22	31.04	32.91	35.57	25.23	30.10	33.52	37.02	41.89	13.76	18.71	22.24	25.65	30.62
Competition	-19.85	-15.37	-12.17	-9.11	-4.32	-51.20	-33.90	-21.88	-9.92	6.60	-31.05	-14.32	-2.85	8.94	26.63
Competition²						-16.26	-1.66	8.87	19.55	34.90	-22.96	-7.36	3.55	14.08	29.46
Industry effects													Yes		

N=260
All estimations done by using MCMC method. Number of draws was set at 11,000; the first 1,000 draws were discarded.
All priors were assumed to follow normal distribution with μ=0 and τ=0.001.

relationship are roughly equal. In other words, the probability of a positive vs. negative effect of competition on both types of process innovations is equal. It has to be noted that this is different from saying, as in a classical approach, that there is no effect at all. Thus, at this example it becomes straightforward that the Bayesian methodology delivers a considerably larger amount of information than single metrics reported in classical inference. Although smaller, the drop in the competition coefficient value in both product innovations specifications does not allow us to make any clear conclusion on the effect of competition on product innovation. The different signs of competition coefficients still remain, but the strength of this relationship becomes much weaker. With respect to the quadratic term of competition variable, it can be said that the inverted U shape established in the first regression remains visible for non-ICT-enabled innovations. For the other type of innovation, the inclusion of additional control variables centres the posterior distribution function around zero.

To some extent, the above results are consistent with the findings of previous studies (e.g. Scherer (1965), Cohen and Levin (1989), Geroski (1994)). Although at a first glance one is able to establish some relationship between competition and innovative activity, once controlled for other elements of technology or industry environment, the initial findings become considerably weaker. An important insight of this study is, however, the finding that, if any, there is no homogeneous relationship between competition and in particular product innovations derived from different technologies. Here, this contrast was demonstrated for ICT- and non-ICT-enabled innovations.

2.5 Conclusions

Concluding, a detailed analysis that takes into account the heterogeneity of innovation activity reveals that there is no simple answer to the question of what is the optimal market structure or competition level for innovation. The results indicate that the statement that there is an inverted U-shape relationship between innovation and competition is only partially true. Such a relation holds only for some types of innovation, e.g. non-ICT-based innovations. For other types of innovations, for example ICT-based innovations, a negative impact of increasing competition on innovative activity can be observed. Consequently, in light of the results of the previous studies, these outcomes cast completely new light on the relationship between innovation and competition. However, similar to some previous studies, our results lead to the conclusion that it is not the competition level that primarily affects innovation activity. As indicated before (e.g. Kamien and Schwartz (1982); Cohen and Levin (1989)), these are other technology- and industry-related elements that influence firms' incentives to innovate.

2.6 Annex: Data and variables

2.6.1 e-Business Watch surveys

e-Business Watch is an observatory initiative launched by the European Commission in late 2001. The e-Business Watch monitors the adoption, development and impact of electronic business practices in different sectors of the European economy. The purpose of the project is to provide reliable and methodically consistent empirical information about the extent, scope, and factors affecting the speed of e-business development at the sector level in an internationally comparative framework, information which have previously not been available from official statistics.

Until the end of 2007, the e-Business Watch initiative had conducted five large scale enterprise survey rounds. Each survey had a different coverage of industrial sectors and countries. The surveys are based on independently drawn random samples from pre-specified country-sector combinations, stratified by three enterprise size classes (less than 49 employees, 50-250 employees, or more than 250 employees) to enable a representative representation of the respective country-sector findings. A consistent survey method was used, interviewing decision makers in companies (e.g. IT managers, managing directors or the owner) by computer-aided telephone interviews (CATI). Each interview collected basic information about the company, including confirmation of sector membership, number of employees, number of establishments, and basic financial information such as turnover development. The majority of questions related to the availability and usage of various ICT and e-business technologies.

During the course of the project, changes have also been made to the questionnaire that was used for the surveys (see: www.ebusiness-watch.org). These changes partially reflected prior experience with survey results, identification of additional aspects that deserved more attention, but also changes in the technological environment due to newly emerging trends that needed to be reflected in the questionnaire. The implemented changes led to inconsistencies between the surveys, which makes them difficult to compare. Only some questions remained unchanged over the entire project life cycle. Thus, in this study we use data from three surveys, i.e. the Nov/Dec 2003, 2005 and 2006 surveys.

Table 2.4: Country-sector coverage e-Business W@tch survey Nov/Dec 2003

	Textile industries	Chemical industries	Electronics	Transport equipment	Crafts & trade	Retail	Tourism	ICT services	Health & social services	Business services
Belgium		100				100				100
Denmark						66	67		67	
Germany	100	100	100	100	100	100	100	100	100	100
Greece	75		75	75	75		75			
Spain	100	100	100	100	100	100	100	100	100	100
France	100	100	100	100	100	100	100	100	100	100
Ireland		70					70	70		
Italy	100	100	100	100	100	100	100	100	100	100
Netherlands	100							100	100	
Austria				100			100		100	
Portugal				100		100				100
Finland	75		75					75		
Sweden		75	75	75						75
United Kingdom	100	100	100	100	100	100	100	100	100	100
Cyprus						50				
Czech Republic		50		50			75	75	50	
Estonia	50	50	50	50	50	50	50	50	50	50
Hungary				80	80					80
Lithuania						50				
Latvia	50	50				50				
Malta							50			
Poland	80	80	80	80	80	80	80	80	80	80
Slovenia			50				50	50	50	50
Slovakia	50		50			50				50
Norway	50					50				

The Nov/Dec 2003 survey covered ten sectors in 25 European countries. In sum, the data set contains 7,302 valid observations. Regarding the geographical scope of the survey, 4,670 were conducted in the old EU and Norway and the remaining 2,632 in the Acceding Countries. Within each sector, sampling was adjusted according to the relative size of sub-sectors measured by value-added. Thus, sub-sectors with a relatively larger share of contribution to national GDP were included with a proportionately larger number of interviews, allowing to get an approximately representative picture at the country-sector level. Table 2.4 shows the number of successfully completed interviews in each country-sector cell for the e-Business Watch survey which was carried out in Nov/Dec 2003. All 10 sectors were covered only in the five largest European countries (France, Germany, Italy, Spain and the UK) and two accessing countries (Estonia and Poland). Consequently, only these seven countries which exhibit a complete and homogeneous sector coverage that enables cross-country and cross-sector comparisons.

Table 2.5: Country-sector coverage e-Business W@tch survey 2005

	Food and beverages	Textile industries	Publishing and printing	Manufacture of pharmaceuticals	Manufacture of machinery and equipment	Automotive industry	Aerospace indstry	Construction	Tourism	IT services
France	80	80	80	76	77	80	39	80	80	78
Germany	80	76	80	83	80	80	38	81	80	80
Italy	86	81	79	81	84	81	23	80	82	82
Spain	82	81	82	81	81	81	15	83	82	82
UK	75	75	75	75	75	75	25	75	76	75
Czech Republic	85	85	84	54	85	85	20	84	84	84
Poland	83	83	83	82	83	83	3	83	83	84
TOTAL	571	561	563	532	565	565	163	566	567	565

The e-Business Survey 2005, which was the third survey after those of 2002 and 2003, had a scope of 5,218 telephone interviews with decision-makers in enterprises from seven EU countries. In contrast to the surveys of 2002 and 2003, the survey of 2005 considered only companies that used computers. Thus, the highest level of the population ("base") was the set of all computer-using enterprises which were active within the national territory of one of the respective countries, and which had their primary business activity in one of the sectors specified by NACE Rev. 1.1 categories. The sample drawn was a random sample of companies from the respective sector population in each of the seven countries, with the objective of fulfilling strata with respect to company size class and no cut-off was made in terms of minimum size of firms. Strata were to include a share of at least 10% of large companies (250+ employees) per country-sector cell, 30% of medium sized enterprises (50-249 employees), 25% of small enterprises (10-49 employees) and up to 35% of micro enterprises with less than 10 employees. Table 2.5 shows the number of successfully completed interviews in each country-sector cell for the survey which was carried out in 2005. Within this survey, all 10 sectors were covered in each country, which gives a complete and homogeneous sector-country coverage.

Table 2.6: Country-sector coverage e-Business W@tch survey 2006

	Food and beverages	Footwear	Pulp and Paper	ICT Manufacturing	Consumer electronics	Shipbuilding and repair	Construction	Tourism	Telecommunications	Hospital activities
France	78	26	132	190	20	8	75	70	72	80
Germany	53	68	163	169	66	15	51	54	60	101
Italy	50	200	85	182	30	21	50	48	50	40
Poland	50	135	75	76	141	3	50	50	75	97
Spain	49	181	117	132	17	23	49	46	103	37
UK	59	20	140	167	59	8	59	57	147	34
Austria	116		20	24			119	121		
Belgium	112			38	9	1	100		118	22
Bulgaria	115	20		25			120	120		
Cyprus	50						79	80		
Czech Republic	74	70	105	99	130	2	75	75	70	50
Denmark	100		30			2	101	110	60	
Estonia				24			120	132	38	
Finland	149	18	66	104	9	4	141	134	95	32
Greece	102	32				1	120	119	17	16
Hungary	153	40	50	95	19	2	152	141	60	60
Ireland	54			36	1		119	178	12	
Latvia				54			130	132	61	55
Lithuania			38	50	15		122		121	58
Luxembourg							62	55		
Malta							33	68		
Netherlands	60	11	31	63	16	12	52	50	97	8
Norway				11		35	184	140	22	9
Portugal	138	50	20			2		140		50
Romania	106		20			4	121	102	87	
Slovakia		32			46		127	150	45	
Slovenia	33		11	21			168	167		
Sweden			55	77	37			126	95	10
Turkey		75		50	50		75		75	75
Total	1701	978	1158	1687	665	143	2654	2665	1580	834

The e-Business Watch survey 2006 was the fourth survey after those of 2002, 2003 and 2005 and had a scope of 14,081 interviews with decision-makers in enterprises from 29 countries, including the 25 EU Member States, EEA and Candidate Countries. The design of the questionnaire builds on the ones used in the previous surveys from 2002 to 2005. As in 2005, the survey considered only companies that used computers. Thus, the highest level of the population was the set of all computer-using enterprises which were active within the national territory of one of the 29 countries covered, and which had their primary business activity in one of the 10 sectors specified on the basis of NACE Rev. 1.1.

No cut-off was made in terms of minimum size of firms. The sample drawn was a random sample of companies from the respective sector population in each of the seven countries, with the objective of fulfilling minimum strata with respect to company size class per country-sector cell. Strata were to include a 10% share of large companies (250+ employees), 30% of medium sized enterprises (50-249 employees), 25% of small enterprises (10-49 employees) and up to 35% of micro enterprises with less than 10 employees. Samples were drawn based on widely recognized business directories and databases. In most countries, between 400 and 750 interviews were conducted. Table 2.6 shows the number of successfully completed interviews in each country-sector cell for the e-Business Watch survey which was carried out in 2006.

2.6.2 Variables description and descriptive statistics

Table 2.7: Variable definitions

Variable	Definition
Competition	The difference between 1 and industry-level gross margins, i.e. the difference between value added and labour cost as a proportion of value added.
Non-ICT-enabled product innovation	If a company introduced new or substantially improved products or services to its customers during the past 12 months, the following question was asked: "Has any of your product / service innovations over the past 12 months been directly related to or enabled by Internet-based technology? (yes / no / don't know, not applicable)". All negative answers were aggregated to form an average value for each market.
ICT-enabled product innovation	If a company introduced new or substantially improved products or services to its customers during the past 12 months, the following question was asked: "Has any of your product / service innovations over the past 12 months been directly related to or enabled by Internet-based technology? (yes / no / don't know, not applicable)". All positive answers were aggregated to form an average value for each market.
Non-ICT-enabled process innovation	If a company introduced new company internal processes during the past 12 months, the following question was asked: "Has any of your product / service innovations over the past 12 months been directly related to or enabled by Internet-based technology? (yes / no / don't know, not applicable)". All positive answers were aggregated to form an average value for each market.
ICT-enabled process innovation	If a company introduced new or substantially improved products or services to its customers during the past 12 months, the following question was asked: "- Has any of your company internal process innovations been directly related to or enabled by Internet-based technology? (yes / no / don't know, not applicable)". All positive answers were aggregated to form an average value for each market.
Source: e-Business Watch surveys are source of all variables, except Competition variable, whose source is EU KLEMS.	

Table 2.8: Descriptive statistics

Variable	N	Mean	Median	S.D.	Min	Max
Non-ICT-enabled product innovation	260	21.58	18.70	13.28	0.00	70.00
ICT-enabled product innovation	260	22.69	18.79	14.62	0.00	85.00
Non-ICT-enabled process innovation	260	13.61	12.37	8.75	0.00	49.00
ICT-enabled process innovation	260	24.17	23.80	11.46	0.00	75.00
Competition	260	0.57	0.58	0.15	0.11	0.97

Table 2.9: Correlation matrix

	Variable	1	2	3	4	5
1	Non-ICT-enabled product innovation	1				
2	ICT-enabled product innovation	-0.38*	1			
3	Non-ICT-enabled process innovation	0.54*	-0.09	1		
4	ICT-enabled process innovation	-0.05	0.49*	-0.18*	1	
5	Competition	0.08	-0.23*	0.11	-0.17*	1
* signifficant at .01 level						

Chapter 3

Value chain structure and flexible production technologies

3.1 Introduction

In this chapter I analyze the interplay between the value chain organization, the adoption of flexible production technologies (FPT) leading to more product variety and welfare implications of such actions. Choosing FPT over dedicated production technology (DPT) allows a manufacturer to gain access to inputs necessary to extend its product variety. In order to link the characteristics of FPT with the firm scope and supplier relations, I develop a theoretical model that allows for an analysis of suppliers' incentives to merge and manufacturers' decisions regarding the choice of production technologies that are specific to inputs produced by suppliers. Two questions are of major importance here: First, how does the structure of the upstream industry, market size and the degree of product differentiation affect producers' incentives to adopt FPT? Second, what are the welfare implications of the decisions regarding investments in the production technologies under different structures of the upstream industry?

The motivation for this analysis is the technological shock that, over the last two decades, has lead to a reorganization of value chain structure and that moves industries away from mass production to mass customization.

Flexible machines and multitasking production equipment replace specialized and single-purpose equipment. Because FPT can be reprogrammed quickly, they can be seen as an ability to produce several products in a single plant or on a single assembly line at a low cost, relatively to the specialized equipment designed for mass production of homogeneous products (Milgrom and Roberts (1990)). Consequently, modern manufacturing is being transformed by the adoption of FPT and complementary changes in firms' strategy and organization. In particular, FPT enable firms to change their strategies and the way they organize their activities within and between organizations. New strategies include broadening product lines, frequent product introductions and improvements. Such behavior is consistent with the argument that, as firms seek to escape competition, implementing technologies that allow for extending product line and increasing product variety is a major point of emphasis in the quest for additional profits (Lancaster (1990)). Regarding organizational changes, a firm's processes, internal structure, and the relationships with outside partners are strongly influenced by its product strategy and technology in place (Brynjolfsson et al. (2002)). Consequently, value chain characteristics and production technology have a considerable impact on the competition in the input and product markets and, eventually, on welfare.

To model the interplay between value chain organization, technology and increasing product variety, regarding the technology characteristics, I follow the assumptions made by Röller and Tombak (1990). In a linear framework, they model FPT as a technology that enables firms to produce parallel two products instead of only one. According to their results, investing in FPT leads to more competition and subsequently reduces prices and profits of both firms. Their conclusion is that flexibility is detrimental to firms' profits and companies are better-off when they remain one-product monopolists. Furthermore, although more flexibility leads to the transfer of surplus from producers to consumers, parallel production of both goods is desirable from the social point of view only when products are enough differentiated (Gupta (1998)).

An alternative treatment of flexible production technologies can be found in Eaton and Schmitt (1994). They use a Hotelling model in which they describe the effects of new production system on firms' ability to lower the cost of product customization and the cost of switching the production process from one variant to another. The focus of their analysis is, however, different from the one of the current work. In their work, they study the implications of flexible manufacturing systems for market structure and find that they promote concentration through preemption and mergers. By using a similar approach, Norman and Thisse (1999) arrive to a conclusion that the monopoly preemption is still feasible, but it will lead to excessive product variety.

Concerning the value chain dimension, I follow Horn and Wolinsky (1988) who model a duopoly in which producers buy inputs through bilateral monopoly relations with suppliers. This setting reflects the vertical relations modelled in this analysis in a state when both downstream firms use dedicated technologies. Analyzing horizontal mergers, they find that the distribution of bargaining power might have important implications for merger incentives. For example, in contrast to the finding of this analysis, they argue that under some conditions duopoly structure might be profit maximizing for the upstream industry. Following this line of analysis, Milliou and Petrakis (2005) modify the bargaining setting and find that under some conditions suppliers prefer to act independently as well.

To my best knowledge, the problem of flexible production technologies in the context of vertical relations has been not analyzed yet. Available literature on vertical relations and technology focuses on supplier-buyer specific investments and the impact of vertical merger on such investments. This approach assumes that technology used by vertically separated firms influences input price, not product variety. For example, Kranton and Minehart (2004) use a framework in which there are two upstream and two downstream firms. Downstream firms compete for one indivisible input unit produced by each supplier. Buyers' valuation of input depends on their investments into supplier-specific assets. Focusing on vertical merger and its effect on downstream investment decisions into assets that are specific to supplier-buyer relations, they find that vertical merger might distort investments into technologies reducing production costs of the remaining firms. Similarly, regarding efficiency-increasing investments, Inderst and Wey (2003) analyze the effect of upstream and downstream market structure on suppliers' innovation investments. They consider technological flexibility in terms of production volume and technology choice that determines the level of production costs. Another work by Inderst and Wey (2007) follows this line and analyzes the question of how the distribution of bargaining power in value chain affects suppliers' incentives to make technological improvements and reduce marginal production costs.

The model developed in this chapter exhibits characteristics of successive monopolies and foreclosure. Regarding the issue of successive monopolies, due to the type of relations between upstream and downstream firms, we can observe a well-known problem of double marginalization (Spengler (1950)). Although designing a remedy to this problem is beyond the scope of this chapter, it is worthwhile to mention that the use of flexible production technologies intensifies competition in the input and consumer market and reduces the harmful effect of double marginalization. Regarding the foreclosure concept, provided that there are cost or technological barriers to procure inputs necessary to broaden a firm's product line, flexible technologies can be seen as a device to bypass foreclosure. Consequently, this links the current analysis to the discussion of vertical foreclosure and incentives to invest (see, for example, Hart et al. (1990), Baake et al. (2003), Fumagalli et al. (2006) and Rey and Tirole (2007).

The current model includes some elements of exclusive dealing and vertical integration as well. These issues are analyzed, for example, by Bonanno and Vickers (1988). By using a two-part tariff contract as a mechanism to set prices, they model two single-product manufacturers that sell their products to independent retailers and analyze what are producers' incentives to vertically integrate or to sell their products through independent retailers. Similar approach can be found, for example, in Rey and Tirole (1986) and Rey and Stiglitz (1988).

Other papers that are closely related to the current one include Lin (1990) and Ziss (1995). The former one models two retail chains and argues that upstream firms choose an exclusive dealing set-up in order to relax intra-brand competition. In the context of the current model, flexible technologies might have pro-competitive effects, as they remove the exclusive dealing constraints, intensify inter-brand rivalry and introduce intra-brand competition. Ziss (1995) explicitly includes the issue of vertical mergers at both levels. His main finding is that both types of merger have anti-competitive effects.

Despite drawing on some already analyzed concepts, the design of the current analysis differs from previous contributions. First, using the framework of complementarity between technology, strategy and organization, I formalize the idea of the adoption of flexible vs. specialized production equipment and link it to firms' strategies regarding broadening product line and their impact on competition at the upstream and downstream level. Second, I discuss the concept of technology as a means to bypass foreclosure and its pro-competitive effects. This casts some new light on how technological progress removes barriers to competition and, consequently, influences social welfare. Lastly, I analyze welfare implications of different technology states under both competitive and monopolistic structure of the upstream industry.

Besides confirming existing findings, the contributions of the analysis are many fold. First, running counter to intuition, the results reveal that increased competition due to the diffusion of FPT might erode any benefits of such technologies. Although the use of FPT might be profitable from a point of view of an individual firm, when all firms in the industry adopt such technologies they collectively forsake profits. Consequently, as there is a coordination problem, firms end up in a Prisoners' Dilemma situation. To a large extent, this confirms the results of Röller and Tombak (1990). Considering the effect of the structure of the upstream industry, I show that under some conditions, i.e. when products are complements, manufacturers are more likely to adopt FPT when there is a multi-product monopolistic supplier of both inputs, as compared to a state with two independent suppliers. The reverse is true when products are substitutes. Second, I show that the introduction of FPT by downstream producers has two effects on the payoff to the upstream industry. On the one hand, selling to both firms increases intra-brand competition and reduces suppliers' profits. On the other hand, suppliers benefit from the pro-competitive effects of FPT on the final market. It seems that the latter effect dominates the former one. Furthermore, regarding suppliers, unlike in Lin (1990), under the current setting suppliers prefer to supply both downstream firms to exclusive interaction with only one of them. Third, the adoption of FPT is always beneficial from the consumers and suppliers point of view. The fact that new technologies have always positive effect on consumer surplus is different from the findings of Röller and Tombak (1990) who concluded that such investments by downstream firms generate benefits to consumers only for sufficiently differentiated products. Furthermore, considering the structure of the upstream industry, I find that a supplier merger increases consumer surplus when products are complements. In total, the diffusion of FPT has a positive impact on total welfare, provided that products are not close substitutes, and for some intermediate values of market size, companies' equilibrium decisions lead to socially inefficient outcomes.

Empirical research confirms that information and communication technologies (ICT) enable firms to expand product variety and to deal with a following raise in the complexity and sophistication of technological and business processes (e.g. Bakos, et al. (1986), Jaikumar, (1986), Holland et al. (1997)). For example, a combination of new computer-based flexible machinery with new work practices allowed a Johnson&Johnson factory to significantly increase the variety of products it could manufacture and reduce costs (Brynjolfsson et al. (2002)). Similar trends can be observed in the electronics industry where the choice of products and their functionalities have been dramatically increasing over the last decades (Petkova (2003)). Dell Computer is a quintessential New Economy company known for its flexibility, leanness, and a variety of products cut to customers' needs. Because of massive investments in ICT, Dell extended the reach and scope of its business at a relatively low cost (Kraemer, et al. (2001)). Sophisticated technologies allowed it to automate business and production functions and to coordinate a network of suppliers and business partners who carry out most of the tasks involved in developing, building and distributing of personal computers.

The impact of new technologies on product variety is not limited to manufacturing industries only. Studies of the financial intermediation, airline, hotel and rental car industries report that systems linking organizations in value chain, i.e. inter-organizational systems or IOS, allow an agent to access quickly a wide range of products offered by different providers and to bundle them in order to create a combination cut to individual customer needs (Hess et al. (1994) or Johnston et al. (1988)). In a study of the causes of Wal-Mart's growth, Basker (2007) cites bar code and RFID as major sources of the retailer's success. The availability of a technology that reduces the inventory tracking costs and improves the overall efficiency of the supply chain increases the incentives to add product lines led directly to the creation of supercenters that sell a full line of groceries in addition to general merchandise. The rapid and ubiquitous spread of ICT and flexible production systems have implications for suppliers of firms implementing them as well. Dewan et al. (1998) analyzes the link between the scale and scope of a firm and its ICT investments with an emphasis on the role of ICT in coordination with suppliers. The results suggest that ICT investments are positively related to the degree of firm diversification. Similarly, Hempell et al. (2005) study how ICT drives product and process innovations by enhancing organizational flexibility. They conclude that by facilitating communication and access to information, ICT favours the use of easily programmable machines and improves the coordination with suppliers. Moreover, ICT increases the organizational flexibility as it allows for a quick reaction to changes in consumer preferences. This additionally increases the incentives to expand the product line.

However, the process of strategy and organizational changes driven by the diffusion of new technologies has consequences that go far beyond the boundaries of firms that adopt them. For example, as firms broadening product line remove the boundaries between separate markets, suppliers of such firms are exposed to stronger competition. Furthermore, an increase in the number of downstream firms demanding inputs might raise supplier's minimum efficient size of operations necessary to satisfy new demand. Thus, it can be expected that when facing stronger pressure from downstream firms, suppliers might preempt such challenges. One way to deal with them is to increase the scale of operations or to reduce the intensity of upstream competition. Both effects can be achieved through a consolidation process. Indeed, it has been observed that firms are going through intensive shakeouts and waves of mergers during periods of especially high demand (Bernile, et al. (2007)). Consequently, if profitable at first glance, the adoption of new production system might not bring the expected payoff once preempted by other partners in the value chain.

The automotive industry provides an interesting example of the relationship between technology, product variety and vertical organization. The consolidation within the automotive suppliers' network is a response to constantly increasing quality demands, taking over more operations in design and production, on the one hand, and to reduce price, on the other hand. Consequently, manufacturers are becoming more dependent on suppliers and suppliers are becoming more involved into development and manufacture of a greater number of products. As a result, the number of automotive suppliers worldwide is expected to shrink by half by 2015 (VDA (2004)). At the same time, new technologies deployed in product design, manufacturing and interactions with suppliers allow car manufacturers to steadily increase the number of car models (Dicken (2003)). In 2002 there were over 1000 car models offered for sale in the United States, double as much as in 1980 (van Biesebroeck (2006)). The answer to the question regarding profitability of such changes is more complex than it seems. For example, since early '90s, the BMW product line has expanded from 5 to 10 lines (PWC, mimeo). At the same time, the production volume reached over 1.3 million in 2005 from 0.5 million units in 1990. Although, between 2001 and 2005, the revenues increased by over 30% to nearly 46 billion Euro, gross margin has in fact declined from 8.3% to 6.5% in the same period. Thus, the changes in vertical structure and the impacts of the diffusion of FPT might go far beyond the increased product variety offered by firms.

The rest of the chapter is organized as follows. Section 3.2 introduces the model. Section 3.3 analyses outcomes that emerge in the current structure and Section 3.4 identifies equilibria. Section 3.5 considers welfare implications of both technology choice and the market structure of the upstream industry. Section 3.6 concludes and suggests some potential extensions to the current analysis. Annex includes proofs.

3.2 The Model

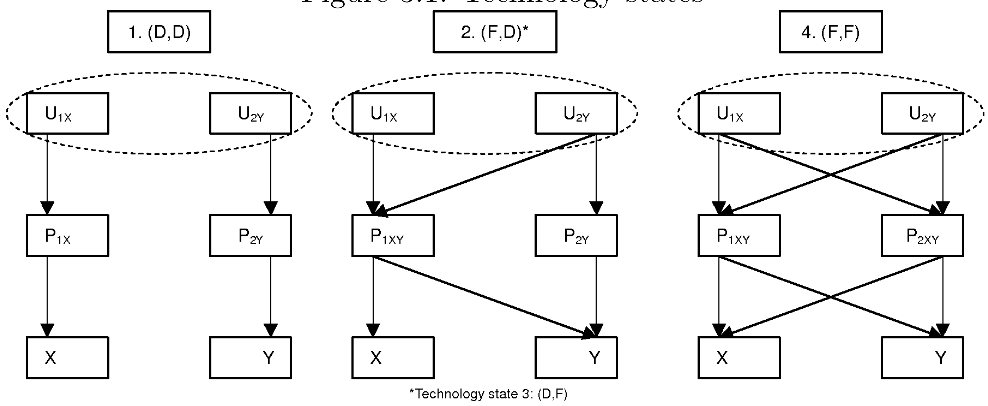
I consider two supply chains in which downstream producers buy inputs from either one or two suppliers. There are two products in the market, X and Y. In order to produce each product, downstream firm needs technology that is specific to the input for a particular product. Figure 3.1 illustrates all possible technology states. If downstream producer P_1 (P_2) uses dedicated technology (D) it can purchase input from upstream supplier U_1 (U_2) and supply final good X (Y). This is case (D,D). If downstream firm uses flexible technology (F) they can be active in both parts of the market (case (F,F)). Mixed outcomes, i.e. (F,D) and (D,F), in which downstream firms can use different technologies are allowed. An identical situation is possible when there is only one supplier of both inputs (dashed circles).

The game has four stages:

- Stage one: Suppliers decide on whether to merge or stay independent.
- Stage two: Producers choose between dedicated and flexible technology.
- Stage three: Suppliers set input prices. I assume that each supplier maximizes his profit with respect to input price, given demand of downstream firms and the strategy of the other supplier. If there is only one multi-product supplier, he maximizes its profit with respect to both input prices.
- Stage four: Producers play a Cournot game on the consumer market.

In contrast to Horn and Wolinsky (1988), I assume that suppliers have all the bargaining power and make take-it-or-leave-it offers to manufacturers. Within this framework, it is very likely that in equilibrium suppliers choose to merge over acting independently. The motivation behind this assumption

Figure 3.1: Technology states



is the question of how technology choices of downstream firms differ with respect to the market structure of the upstream industry.

In order to describe the market demand for product X and Y, I follow Matutes et al. (1989) and assume some degree of product differentiation. For each of the two goods consumers maximize a utility function that is separable in the numeraire good M:

$$V[X, Y, M] = U(X, Y) + M \tag{3.1}$$

where X and Y are the total quantities of both products. Let the quadratic utility function be given by:

$$U = \alpha(X + Y) - \frac{1}{2}(X^2 + Y^2 + 2\gamma XY), \tag{3.2}$$

then the first order conditions of the consumer maximization problem yield the following demand functions:

$$p^X = \alpha - \gamma Y - X \text{ and } p^Y = \alpha - \gamma X - Y \tag{3.3}$$

where p^X and p^Y are the prices for product X and Y. $X = x_1 + x_2$ and $Y = y_1 + y_2$ are the total quantities of product X and Y produced by downstream firm $i = 1, 2$. Parameter γ can be interpreted as a determinant of product differentiation. Products are complements when $-1 \leq \gamma < 0$ and substitutes when $0 < \gamma \leq 1$. If $\gamma = 0$, product are not related. These conditions guarantee that the own price effect is always stronger than the cross-price effect. The vale of α can be interpreted as the potential size of the market.

Regarding the cost structure, I assume that suppliers do not incur any costs and that the cost of inputs is the only marginal cost of producers. Thus, given the above defined demand system and cost structure, the payoff function of each downstream firm $i = 1, 2$ is:

$$\pi_{i,j}^{Pk} = (p_j^{Xk} - w_j^{Xk})x_{ij}^k + (p_j^{Yk} - w_j^{Yk})y_{ij}^k - f_t \tag{3.4}$$

where P denotes downstream firm and $k = I, M$ represents the structure of the upstream industry where I denotes independent suppliers and M a multi-product monopolistic supplier. Technology choice of downstream producers is denoted by $j = 1, ..., 4$ where $j = 1$ indicates that both firms invest in dedicated technologies (D, D), $j = 2$ when firm 1 invests in technology F and firm 2 in technology D, (F, D). In this case, firm 2 procures input only from supplier 2 and firm 1 from both of them. The reverse is true in $j = 3$ when firm 2 chooses technology F and firm 1 technology D, (D,F). The last case, $j = 4$, is when both firms invest in technology F, (F, F). This means that both downstream firms can procure inputs for both products. Input prices for product X and Y are given by w^{Xk} and w^{Yk} respectively. f_t is the fixed cost of the production technology $t = D, F$ that downstream firms need to incur. Let the cost of dedicated technology be $f_D = 1$ and the cost of flexible technology $f_F = 1 + s$. To make it realistic, I assume that technology F is more costly than technology D, i.e. $s > 0$. Both production technologies exhibit constant returns to scale, i.e. out of one unit of input downstream firm produces one unit of output. As tie-breaking rules, if downstream producer is indifferent between technologies it will choose flexible one.

The payoff function of independent upstream firms $i = 1, 2$ is given by:

$$\pi_{1,j}^{U} = w_j^{Xk} X_j^k \text{ and } \pi_{2j}^{U} = w_j^{Yk} Y_j^k \tag{3.5}$$

where U denotes upstream firm. Supplier 1 produces input for final product

X and supplier 2 for final product Y. A single supplier faces the following maximization problem

$$\pi_{M,j}^{U} = w_j^{Xk} X_j^k + w_j^{Yk} Y_j^k \tag{3.6}$$

where M denotes a multiproduct monopolistic supplier. Whenever suppliers are indifferent between merging or remaining independent they will merge. Table 3.1 exhibits the payoffs to downstream and upstream firms in all possible settings.

Table 3.1: Technology choice and firms' payoffs

		Firm 2	
		D	F
Firm 1	D	$(\pi_{11}^{Pk}, \pi_{21}^{Pk}), (\pi_{11}^{U}, \pi_{21}^{U})$ or π_{M1}^{U}	$(\pi_{13}^{Pk}, \pi_{23}^{Pk}), (\pi_{13}^{U}, \pi_{23}^{U})$ or π_{M1}^{U}
	F	$(\pi_{12}^{Pk}, \pi_{22}^{Pk}), (\pi_{12}^{U}, \pi_{22}^{U})$ or π_{M1}^{U}	$(\pi_{14}^{Pk}, \pi_{24}^{Pk}), (\pi_{14}^{U}, \pi_{24}^{U})$ or π_{M1}^{U}

3.3 Input prices and product quantities

Except for the whole game, there are two sub-games. One with independent suppliers of each intermediary product and one with a multi-product upstream monopoly. Depending on the technology choice, there are four possible outcomes at the downstream level. By using backward induction, in the following section I solve the game for the final quantities and input prices that arise in each technology state under both structures of the upstream industry. Then, I use these results to find a sub-game perfect equilibrium of the merger and technology game.

3.3.1 Independent suppliers

Technology outcome (D,D): In the first case, (D, D), both manufacturers use dedicated technologies and supply only one product. Firm 1 produces good X and firm 2 produces good Y. In this case, firm 1 interacts with supplier 1 and firm 2 with supplier 2. Both downstream firms have symmetric profit functions of the form:

$$\pi_{11}^{PI} = (p_1^{XI} - w_1^{XI})x_{11}^I - 1 \text{ and } \pi_{21}^{PI} = (p_1^{YI} - w_1^{YI})y_{21}^I - 1. \quad (3.7)$$

Solving for Cournot equilibrium outcomes, yields symmetric quantities:

$$x_{11}^{I*} = \frac{\alpha(\gamma-2) - \gamma w_1^{YI} + 2w_1^{XI}}{\gamma^2 - 4} \text{ and } y_{21}^{I*} = \frac{\alpha(\gamma-2) - \gamma w_1^{XI} + 2w_1^{YI}}{\gamma^2 - 4}. \quad (3.8)$$

As one piece of input is used up to produce one piece of output, quantities produced by manufacturers are at the same time the demanded quantities for inputs. Thus, by maximizing their profit functions with respect to w_1^{XI} and w_1^{YI}, suppliers set symmetric prices for product X and Y:

$$w_1^{XI*} = w_1^{YI*} = \frac{\alpha(\gamma-2)}{\gamma-4}. \quad (3.9)$$

Substituting input prices into the reaction functions of downstream firms leads to the following expression:

$$x_{11}^{I*} = y_{21}^{I*} = \frac{2\alpha}{(\gamma+2)(4-\gamma)}. \quad (3.10)$$

In other words, both firms produce identical quantities of the final products.

Technology outcome (F,D) or (D,F): In the second and third case, asymmetric outcomes arise, i.e. when one downstream firm uses dedicated and the other one flexible technology. Let us consider the (F,D) outcome when firm 1 uses technology F and firm 2 technology D. In this case, manufacturer 1 is able to interact with supplier 1 and 2. As a result, it produces X and Y. Manufacturer 2, in contrast, procures only from supplier 2 and produces product Y only. Thus, the payoff functions of manufacturers are asymmetric, i.e.

$$\pi_{12}^{PI} = (p_2^{XI} - w_2^{XI})x_{12}^I + (p_2^{YI} - w_2^{YI})y_{12}^I - (1+s) \quad (3.11)$$

$$\text{and } \pi_{22}^{PI} = (p_2^{YI} - w_2^{YI})y_{22}^{I} - 1. \tag{3.12}$$

By maximizing the above expression with respect to x_{12}^I, y_{12}^I and y_{22}^I, one obtains the following reaction functions:

$$x_{12}^{I*} = \frac{\alpha(\gamma - 1) - \gamma w_2^{YI} + w_2^{XI}}{2(\gamma^2 - 1)} \tag{3.13}$$

$$\text{and } y_{12}^{I*} = \frac{\alpha(\gamma^2 - 3\gamma + 2) - \gamma^2 w_2^{YI} + 3\gamma w_2^{XI} - 2w_2^{YI}}{6(1 - \gamma^2)},\ y_{22}^{I*} = \frac{\alpha - w_2^{YI}}{3}. \tag{3.14}$$

The above quantities enter the profit functions of upstream firms, which maximize them with respect to input prices w_2^{XI} and w_2^{YI}. As a result, asymmetric prices for X and Y arise:

$$w_2^{XI*} = \frac{\alpha(\gamma^3 - 5\gamma^2 - 4\gamma + 8)}{16 - 7\gamma^2} \text{ and } w_2^{YI*} = \frac{\alpha(5\gamma^2 + 3\gamma - 8)}{7\gamma^2 - 16}. \tag{3.15}$$

By substituting input prices into the reaction functions of downstream firms, one obtains the following equilibrium quantities:

$$x_{12}^{I*} = \frac{\alpha(\gamma^2 - 4\gamma - 8)}{2(\gamma + 1)(7\gamma^2 - 16)}, \tag{3.16}$$

$$\text{and } y_{12}^{I*} = \frac{\alpha(\gamma^3 + 10\gamma^2 + 2\gamma - 16)}{6(\gamma + 1)(7\gamma^2 - 16)},\ y_{22}^{I*} = \frac{\alpha(2\gamma^2 - 3\gamma - 8)}{3(7\gamma^2 - 16)}. \tag{3.17}$$

It is straightforward, that the demand for input Y is higher than for input X. Consequently, supplier 2 earns a higher profit because it sells inputs to both downstream firms.

In the third case, (D, F), the reverse of the (F,D) state is true. That is, $\pi_{13}^{PI} = \pi_{22}^{PI}$ and $\pi_{23}^{PI} = \pi_{12}^{PI}$ at the downstream level, and $\pi_{13}^{U} = \pi_{22}^{U}$ and $\pi_{23}^{U} = \pi_{12}^{U}$ at the upstream level.

Technology outcome (F,F): In the fourth technology case, (F, F), both manufacturers invest in F technology and each of them procures both inputs and produces X and Y. Consequently, manufacturers maximize symmetric profit functions with respect to x_{i4}^I and y_{i4}^I:

$$\pi_{14}^{PI} = (p_4^{XI} - w_4^{XI})x_{14}^I + (p_4^{YI} - w_4^{YI})y_{14}^I - (1+s) \tag{3.18}$$

$$\text{and } \pi_{24}^{PI} = (p_4^{XI} - w_4^{XI})x_{24}^I + (p_4^{YI} - w_4^{YI})y_{24}^I - (1+s). \tag{3.19}$$

This gives symmetric quantities of x_{i4}^I and y_{i4}^I manufactured by downstream firms, i.e.:

$$x_{14}^{I*} = x_{24}^{I*} = \frac{\alpha(\gamma-1) - \gamma w_4^{YI} + w_4^{XI}}{3(\gamma^2-1)} \tag{3.20}$$

$$\text{and } y_{14}^{I*} = y_{24}^{I*} = \frac{\alpha(\gamma-1) - \gamma w_4^{XI} + w_4^{YI}}{3(\gamma^2-1)}. \tag{3.21}$$

In contrast to the (D,D) outcome, suppliers deliver their inputs to both downstream firms and their profit functions can be expressed as

$$\pi_{14}^U = w_4^{XI}(x_{14}^I + x_{24}^I) \tag{3.22}$$

$$\text{and } \pi_{24}^U = w_4^Y(y_{14}^I + y_{24}^I). \tag{3.23}$$

Again, this leads to symmetric input prices for X and Y:

$$w_4^{XI*} = w_4^{YI*} = \frac{\alpha(\gamma-1)}{\gamma-2} \tag{3.24}$$

and eventually symmetric quantities sold on the final market are:

$$x_{14}^{I*} = x_{24}^{I*} = y_{14}^{I*} = y_{24}^{I*} = \frac{\alpha}{3(2-\gamma)(\gamma+1)}. \tag{3.25}$$

3.3.2 A monopolistic multiproduct supplier

Technology outcome (D,D): As in the case with independent suppliers, downstream firms have symmetric profit functions (3.7) and, consequently, symmetric reaction functions (3.8). A multiproduct single supplier sets both input prices at the highest possible level, i.e. $w_1^{XM} = w_1^{YM} = \frac{\alpha}{2}$. The resulting equilibrium quantities are

$$x_{11}^{M*} = y_{21}^{M*} = \frac{2\alpha}{2(\gamma+2)}. \tag{3.26}$$

Technology outcome (F,D) or (D,F): Again, in the asymmetric case, a monopolistic supplier takes the demand of manufacturers given by (3.13) and (3.14) and maximizes its profit by setting monopolistic prices for both inputs. Thus, substituting input prices into the reaction functions of downstream firms leads to the following expression:

$$x_{12}^{M*} = \frac{\alpha}{4(\gamma+1)}, \tag{3.27}$$

$$\text{and } y_{12}^{M*} = \frac{\alpha(2-\gamma)}{12(\gamma+1)},\ y_{22}^{M*} = \frac{\alpha}{6}. \tag{3.28}$$

In the (D, F) case, the reverse of the second state is true, i.e. $x_{13}^{M*} = y_{22}^{M*}, x_{23}^{M*} = y_{12}^{M*}, y_{23}^{M*} = x_{12}^{M*}, \pi_{13}^{PM} = \pi_{22}^{PM}$ and $\pi_{23}^{PM} = \pi_{12}^{PM}$ at the downstream level, and $\pi_{M3}^{U} = \pi_{M2}^{U}$ at the upstream level.

Technology outcome (F,F): Similarly as above, the monopolistic supplier maximizes its total profit by setting monopolistic input prices for both products. The final outcome of the Cournot competition by downstream firms can be expressed as

$$x_{14}^{M*} = x_{24}^{M*} = y_{14}^{M*} = y_{24}^{M*} = \frac{\alpha}{6(\gamma+1)}. \tag{3.29}$$

Table 3.4 and 3.5 (annex) present equilibrium expressions for all possible technology states when suppliers stay independent or when they merge.

3.4 Equilibrium analysis

By comparing equilibrium profits in each market structure and technology outcome, I look for a sub-game perfect equilibrium. In addition, this section discusses the impact of technology cost, market size and the degree of product differentiation on the choice of upstream market structure and the adoption of production technology.

3.4.1 Independent suppliers

This section deals with the sub-game with a competitive structure of the upstream industry. After suppliers chose to stay independent in the first stage, producers choose between FPT and DPT in the second stage. Subsequently, each supplier maximizes its profit with respect to input price, given quantities ordered by downstream firms and the strategy of the other supplier. In the last stage, downstream producers compete in a Cournot game.

Independent suppliers and (D, D) equilibrium: The state with two independent suppliers and downstream firms choosing dedicated technologies is an equilibrium when two conditions are satisfied. First, from table 3.1 we see that both downstream firms choose D technology when

$$\pi_{12}^{PI} - \pi_{11}^{PI} < 0 \text{ and } \pi_{23}^{PI} - \pi_{21}^{PI} < 0. \tag{3.30}$$

This can be expressed as:

$$f_{DD}^{I}(\gamma) - \frac{s}{\alpha^2} < 0 \tag{3.31}$$

where

$$f_{DD}^{I}(\gamma) = \frac{(\gamma^7 + 3\gamma^6 - 68\gamma^5 + 8\gamma^4 - 176\gamma^3 - 832\gamma^2 - 1152\gamma - 1024)}{36(\gamma+1)(\gamma-4)^2(\gamma+2)^2(7\gamma^2-16)} \tag{3.32}$$

Second, for the equilibrium to exist, profits of independent suppliers must be higher than this of a monopolistic supplier. This is true when

$$\pi_{11}^U + \pi_{21}^U > \pi_{M1}^U. \tag{3.33}$$

This condition is satisfied if

$$\frac{a^2\gamma^2}{2(\gamma+2)(\gamma-4)^2} < 0. \tag{3.34}$$

Regarding the choice of technology, expression (3.31) suggests that both buyers remain using D technologies when α is small and s is high. In other words, small market size discourages firms from entering the part of the market dominated by the other firm. Each firm prefers to stay a one-product monopolist rather than to get involved into direct competition with the other firm. Large values of s additionally discourage firms investments into flexible production systems.

Turning to the second condition (3.34), it is known from Salant (1983) that merger to monopoly is always profitable. This result holds when all the firms collude, so that there are no outsiders. In this case, there are only two firms and it can be seen that whenever products X and Y are complements or substitutes, i.e. $\gamma \in [-1, 1]$, (3.34) is always positive and suppliers choose to merge.

Independent suppliers and (F, F) equilibrium: The state with two independent suppliers and both downstream firms choosing flexible technology is an equilibrium when two conditions are satisfied. First, from table 3.1 we see that both downstream firms choose F technology when

$$\pi_{14}^{PI} \geq \pi_{12}^{PI} \text{ and } \pi_{24}^{PI} \geq \pi_{23}^{PI}. \tag{3.35}$$

This condition is satisfied if

$$f_{FF}^I(\gamma) - \frac{s}{\alpha^2} \geq 0 \tag{3.36}$$

where

$$f^I_{FF}(\gamma) = \frac{(256 - 192\gamma - 164\gamma^2 + 128\gamma^3 - 35\gamma^4 - 13\gamma^5 + 24\gamma^6 - 4\gamma^7)}{9(\gamma+1)(\gamma-2)^2(7\gamma^2-16)^2}. \tag{3.37}$$

Second, profits of independent suppliers must be higher than a monopolist's payoff. This is true when

$$\pi^U_{14} + \pi^U_{24} > \pi^U_{M4} \tag{3.38}$$

which can be expressed as:

$$\frac{\alpha^2\gamma^2}{3(\gamma-2)^2(\gamma+1)} < 0. \tag{3.39}$$

In line with the above case, both producers will switch to technology F when α is large. In other words, large market size gives firms a strong incentive to produce both products and to get involved into direct competition with the other firm. The revenue generated from the sales of the additional product compensate the losses from more intense competition and lower prices. Of course, high technology cots reduces the gains from an increased product variety.

Regarding the upstream market structure, as in the previous case condition (3.39) is fulfilled for all values of γ. Thus, suppliers always choose to merge, given that they are price setters in the input market.

Independent suppliers and mixed equilibria: In (F, D) or (D, F) equilibrium, producer 1 uses technology F and producer 2 technology D or the other way around. Such mixed equilibria exist when two conditions are satisfied. First, from table 3.1 we know that (F, D) or (D, F) is an equilibrium when

$$\pi^{PI}_{12} - \pi^{PI}_{11} \geq 0 \text{ and } \pi^{PI}_{24} - \pi^{PI}_{22} < 0 \tag{3.40}$$

and

$$\pi^{PI}_{14} - \pi^{PI}_{13} < 0 \text{ and } \pi^{PI}_{23} - \pi^{PI}_{21} \geq 0. \tag{3.41}$$

This can be expressed as:

$$f^I_{DD}(\gamma) - \frac{s}{\alpha^2} \geq 0 \tag{3.42}$$

and

$$f^I_{FF}(\gamma) - \frac{s}{\alpha^2} < 0. \tag{3.43}$$

Second, profits of independent suppliers must be higher than this of a monopolistic supplier. This is true when

$$\pi^U_{12} + \pi^U_{22} > \pi^U_{M2} \text{ and } \pi^U_{13} + \pi^U_{23} > \pi^U_{M3}. \tag{3.44}$$

This condition is satisfied if

$$\frac{\alpha^2\gamma^2(112 + 112\gamma + 5\gamma^2 - 13\gamma^3)}{8(\gamma+1)(7\gamma^2 - 16)^2} < 0. \tag{3.45}$$

Regarding the technology choice of downstream companies, these subgame equilibria would result in the region between condition (3.31) and (3.36). However, because the pay-off to the multi-product monopolistic supplier is always higher than to the independent suppliers and upstream firms choose to merge. Consequently, expression (3.45) is positive for all values of α and γ and there is no equilibrium with a competitive structure of the upstream industry. In conclusion, the analysis of the above equilibrium conditions can be summarized in the following Lemma:

> **Lemma 1:** *For all values of α, γ and s, suppliers choose to merge and there is no equilibrium with a competitive upstream market structure.*

Proof: The proof emerges from the suppliers' profit conditions, i.e. condition (3.34), (3.39) and (3.45) are never satisfied. In other words, the profit of a multiproduct monopolistic supplier is never smaller than the cumulative profit of independent suppliers. The same result can be found in Salant (1983). Consequently, there is no outcome with a competitive upstream market structure in the equilibrium.

3.4.2 A single supplier

This section analyses candidate equilibria that emerge given the upstream industry was monopolized in the first stage of the game. Proceeding as above, the game is solved by backward induction. After suppliers decided to merge in the first stage, downstream firms choose production technology in the second stage. Subsequently, a monopolist supplier maximizes its profit function with respect to input prices given quantities ordered by downstream firms. In the last stage manufacturers set the quantities of the final goods in a Cournot game.

A single supplier and (D, D) equilibrium The state with one supplier and downstream firms choosing dedicated technology is an equilibrium when two conditions are satisfied. First, both downstream firms choose D technology when the following condition holds:

$$f^M_{DD}(\gamma) - \frac{s}{\alpha^2} < 0 \tag{3.46}$$

where

$$f^M_{DD}(\gamma) = \frac{(16 - 4\gamma - 7\gamma^2 - 5\gamma^3)}{144(\gamma+1)(\gamma+2)^2}. \tag{3.47}$$

Second, suppliers merge if the monopolistic profit is higher than the profits of the two sellers. This condition is fulfilled if

$$\frac{\alpha^2\gamma^2}{2(\gamma+2)(\gamma-4)^2} \geq 0. \tag{3.48}$$

From the above analysis we know that condition (3.46) depends on the degree of product differentiation, market size and the cost of F technology. The smaller the market and the higher the cost of F technology relatively to D technology, the more are downstream firms inclined to stay with D technology. Regarding the upstream firms, profit of a single supplier is always higher than the profits of separate firms and, consequently, suppliers choose to merge.

A single supplier and (F, F) equilibrium The state with one supplier and both downstream firms choosing F technology is an equilibrium when two conditions are satisfied. First, downstream firms choose F technology when

$$f_{FF}^{M}(\gamma) - \frac{s}{\alpha^2} \geq 0 \tag{3.49}$$

where

$$f_{FF}^{M}(\gamma) = \frac{(1-\gamma)}{36(\gamma+1)}. \tag{3.50}$$

Second, profit of a monopolistic supplier is higher than profits of independent suppliers when

$$\frac{\alpha^2\gamma^2}{3(\gamma-2)^2(\gamma+1)} \geq 0. \tag{3.51}$$

Considering condition (3.49), the choice of F technology is again dependent on the market size, the degree of product differentiation, and the cost of flexible technology. However, although a larger market size encourages both firm to switch to flexible technology and to produce both products, the incentive to expand is reduced by the cost of the new technology. The effect of γ is equally important for the technology choice. It is easy to see that the expansion strongly depends on the degree of product differentiation. Regarding the merger incentive, we know that (3.51) is positive for all values of γ. Thus, suppliers always choose to merge.

A single supplier and mixed equilibria: The state with one supplier and downstream firms choosing different technologies is an equilibrium when two conditions are satisfied. First, from table 3.1 we see that (F, D) or (D, F) are selected when

$$f_{DD}^{M}(\gamma) - \frac{s}{\alpha^2} \geq 0 \tag{3.52}$$

and

$$f_{FF}^{M}(\gamma) - \frac{s}{\alpha^2} < 0. \tag{3.53}$$

Second, the profit of a monopolistic supplier is higher than the profits of independent suppliers when

$$\frac{\alpha^2\gamma^2(112 + 112\gamma + 5\gamma^2 - 13\gamma^3)}{8(\gamma + 1)(7\gamma^2 - 16)^2} \geq 0. \tag{3.54}$$

Considering that (3.54) is positive for all γ and, consequently, that suppliers always merge, mixed equilibria would result in the region between condition (3.53) and (3.54). Both conditions are satisfied when firms sell complementary products. Thus, unlike in Röller and Tombak (1990), for some values of α and γ, mixed equilibria can emerge (see also Kim et al. (1992) and Gupta (1993)).

The analysis of the above equilibrium conditions can be summarized in the following lemma:

> **Lemma 2:** *Suppliers always choose to merge. The technology choice of downstream firms depends on α, γ and s.*

Proof: In the previous sub-section, I proved that conditions (3.34), (3.39) and (3.45) are never satisfied and, therefore, suppliers always prefer to merge to act independently. Regarding the choice of technology by downstream firms, it can be seen from condition (3.46) and (3.49) that the incentives to choose particular technology vary with α, γ and s. Concluding, Lemma 1 and Lemma 2 can be summarized in the following proposition:

> **Proposition 1:** *In equilibrium, suppliers choose to merge. The technology choice of downstream firms depends on the size of the market, the degree of product differentiation and the technology cost in the following way:*
>
> - *(D,D) is an equilibrium if* $\alpha < \sqrt{\frac{s}{f^M_{DD}(\gamma)}}$,
> - *(F,F) is an equilibrium if* $\alpha \geq \sqrt{\frac{s}{f^M_{FF}(\gamma)}}$,
> - *and (F,D) or (D,F) arise in equilibrium when* $\sqrt{\frac{s}{f^M_{DD}(\gamma)}} \leq \alpha < \sqrt{\frac{s}{f^M_{FF}(\gamma)}}$.

Figure 3.2: Equilibrium regions given independent (i) and monopolistic (m) supplier (s=0.5)

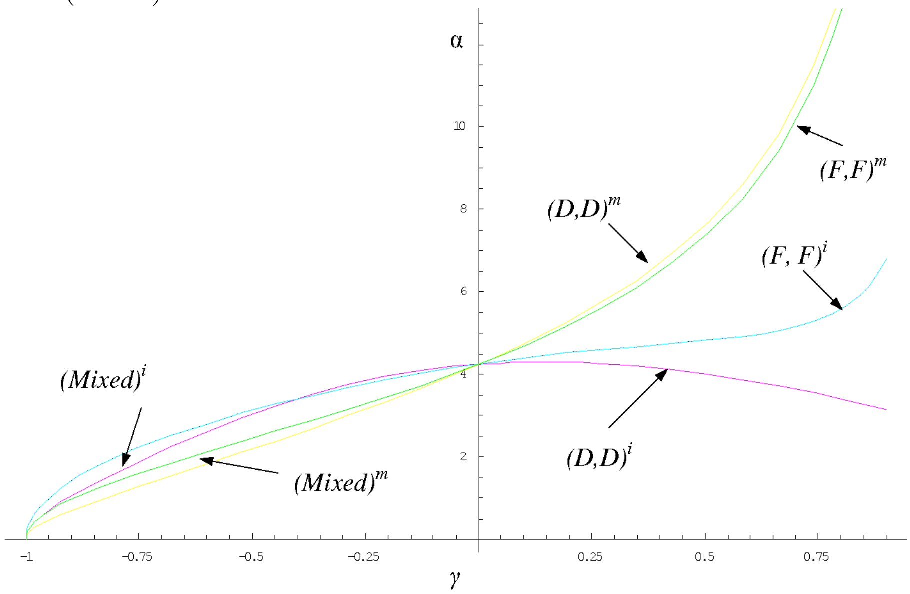


Figure 3.2 illustrates equilibrium regions for all technology choices in α and γ for a value of $s = 0.5$. To check the robustness of the results, the figure was plotted for various parameters of s. The results are not sensitive to the changes of parameter values. For illustrative purposes, I include equilibrium outcomes that would emerge under the competitive structure of the upstream industry. Let us consider first the sub-game with two independent suppliers. The region below the (D,D)^i curve includes the technology state in which both downstream firms remain with dedicated technology. The surface above the (F,F)^i curve shows the technology state in which both firms switch to flexible technology. The area between (D,D)^i and (F,F)^i includes mixed technology choices. It can be seen that, if there were two suppliers, all possible combinations of technology usage patterns could emerge. For example, when products X and Y are complements mixed outcomes would exist for $\gamma \in [-1, -0.41]$. That is, one firm would invest into FPT whereas the other one would remain with specialized equipment. Similarly, mixed outcomes could emerge for substitutable products. Then, both companies would invest into flexible production technologies only when market was sufficiently

large. Otherwise either one or both firms would remain with specialized equipment. For $\gamma \in [-0.41, 0]$ both equilibria could exist, i.e. (D,D) and (F,F).

Investment decisions look slightly different when there is a multi-product monopolistic supplier. Similar as above, the region below the $(\text{D,D})^m$ curve includes the technology state in which both downstream firms remain with dedicated technology. The surface above the $(\text{F,F})^m$ curve shows the technology state in which both firms use flexible technology. The area between $(\text{D,D})^m$ and $(\text{F,F})^m$ includes mixed technology outcomes. Again, we can observe that all technology choices can emerge in equilibrium. For example, mixed equilibria exist only when products are complements. For substitutable products only (F,F) or (D,D) emerge in equilibrium. Furthermore, for $\gamma \in [0, 1]$ two equilibria exist and companies face a coordination problem for some values of α.

As it emerges from the above analysis, it is quite striking how the degree of product differentiation influences the decision to adopt flexible technologies under different structures of the upstream industry. Compared to a situation when there are two independent suppliers, when manufacturers produce complementary products they are more likely to adopt F technology in small markets under monopolistic upstream market structure. This is, however, reversed when products are substitutes. Then FPT would be adopted in much smaller markets if supplier acted independently.

In conclusion, taking into account all possible outcomes, in equilibrium there is a monopolistic supplier of both products. The final outcome regarding the choice of production is less obvious and depends on the values of γ, α and s, i.e. it is a function of market size, the degree of product differentiation and the cost difference between dedicated and flexible production technology.

3.5 Welfare implications

3.5.1 Consumer surplus

Considering that there are linear demand functions for product X and Y, consumer surplus is given by the difference between consumers' utility and the total expenses for purchased goods. Thus, the combined consumer surplus for a given technology state j is given by:

$$CS_j^k = \frac{1}{2}((X_j^k)^2 + (Y_j^k)^2) + \gamma X_j^k Y_j^k \tag{3.55}$$

where X_j^k and Y_j^k are the equilibrium total quantities of product X and Y under upstream market structure $k = I, M$ and technology state j. Equilibrium values of consumer surplus are given in Table 3.2.

Table 3.2: Consumer surplus

Independent suppliers	
(D,D)	$\frac{4\alpha(\gamma+1)}{(\gamma-4)^2(\gamma+2)^2}$
Mixed equilibrium	$\frac{\alpha^2(55\gamma^5-47\gamma^4-632\gamma^3-176\gamma^2+1792\gamma+1600)}{72(\gamma+1)(7\gamma^2-16)^2}$
(F,F)	$\frac{4\alpha^2}{9(\gamma+1)(\gamma-2)^2}$
A single supplier	
(D,D)	$\frac{\alpha^2(\gamma+1)}{4(\gamma+2)^2}$
Mixed equilibrium	$\frac{\alpha^2(7\gamma+25)}{288(\gamma+1)}$
(F,F)	$\frac{\alpha^2}{9(\gamma+1)}$

An analysis of the consumer surplus equilibrium values leads to the following lemma:

Lemma 3: *If CS_j^k is the total consumer surplus in technology state j under upstream market structure k, then:*

a) $CS_4^I \geq CS_2^I = CS_3^I \geq CS_1^I$;

b) $CS_4^M \geq CS_2^M = CS_3^M \geq CS_1^M$;

c) $CS_4^I \geq CS_4^M$ if $\gamma \in [0, 1]$;

d) $CS_4^I \leq CS_4^M$ if $\gamma \in [-1, 0]$.

Proof. See annex.

Results (a) and (b) imply that consumer surplus is always maximized when downstream firms extend their product range. In other words, consumers benefit from an increased competition that results from firms' decisions to serve both parts of the market. If there were two independent input suppliers, the introduction of flexible production systems would introduce intra-brand competition and intensify inter-brand rivalry as well. When the upstream industry is monopolized the main trigger of consumer welfare increase is the intensified competition in the final product market. Consequently, the structure of the upstream industry does not have any effect on consumer surplus when only the technology states are considered. It should be noted that this is true for all types of products.

Although intuitively straightforward, this finding is slightly different from the result in Röller et al. (1990), Gupta (1993) and Gupta (1993). They show that consumer surplus is maximized in (F,F) technology state only for $0 < \gamma \leq 0.80$. In other words, the use of FPT decreases consumer surplus when product X and Y are close substitutes. Under the current setting, however, consumer surplus is the highest when both producers use FPT over the entire range of γ. Consequently, I show that it is always desirable to adopt FPT from the consumers' point of view. This is due to the fact that this type of technologies enable firms to cross the boundaries of the originally separated parts of the market, which in turn leads to more competition among firm that were previously isolated from each other and thereby lower prices. This result holds even when the upstream industry is monopolized.

This finding is different from the conclusion made by Norman and Thisse (1999) as well. According to them, consumers might not benefit from tougher competition. Within the current setting, however, one can conclude that consumers always get the benefit of an increased competition between manufacturers. The source of this discrepancy is the difference in model setting and in the scope of analysis. In particular, they analyze the impact of the introduction of flexible technologies on entry, an issue not covered here, and find that this type of manufacturing deters entry. This, in turn, reduces the pro-competitive effect of flexibility.

In conclusion, the results regarding the use of technology can be summarized in the following proposition:

> **Proposition 2:** *The use of FPT always maximizes consumer surplus.*

Proof: The proof of this proposition follows directly from the results described above and summarized in Lemma 3.

Considering the effect of the upstream industry structure on consumer surplus, the above discussion suggests that consumer surplus should be maximized under competitive conditions. However, this depends on the type of products. Results (c) and (d) imply that, on the one hand, when products are substitutes, a competitive market structure of the input market would lead to the maximization of the consumer surplus. On the other hand, however, when products are complements consumer surplus is maximized when there is a single supplier of both inputs. This indicates that upstream merger might be desirable from the consumers' point of view when products are complements. The source of this positive effect of the monopolization of the input industry is that, when products are complements, monopolistic input price is always lower than the price set by independent suppliers. To see this, one needs to consider the difference between input prices under both upstream market structures. For the (D,D) technology state and for the (F,F) technology state the following conditions are always fulfilled for complementary products: $w_1^{XI*} - \frac{\alpha}{2} \geq 0 \Leftrightarrow \frac{\alpha\gamma}{2(\gamma-4)} \geq 0$ and $w_4^{XI*} - \frac{\alpha}{2} \geq 0 \Leftrightarrow \frac{\alpha\gamma}{2(\gamma-2)} \geq 0$. In a mixed case, this effect exists only for the input for which there is a demand from two suppliers, i.e. in the (F,D) technology state $w_2^{XI*} - \frac{\alpha}{2} \leq 0 \Leftrightarrow \frac{\alpha(32+8\gamma+3\gamma^2-2\gamma^3}{2(7\gamma^2-16)} \leq 0$ and, as above, $w_2^{YI*} - \frac{\alpha}{2} \geq 0 \Leftrightarrow \frac{3\alpha\gamma(2+\gamma)}{2(7\gamma^2-16)} \geq 0$.

3.5.2 Producer surplus

Although it might be intuitively justified for downstream firms to extend their product range, the profitability of such a move needs to be verified in light of adverse impacts they might have on the competition in the final product market and in the input market. Thus, the following section analyses the payoffs to the upstream and downstream industries in different equilibria and, in addition, compares them with the outcomes under a competitive structure of the upstream industry. I first look at the payoffs of upstream firms and then turn to the surplus of downstream companies. The total profits of the upstream and downstream industry are presented in annex (see Table 3.4 and Table 3.5).

Upstream firms

The introduction of FPT by downstream firms should increase the demand for intermediary products. However, when downstream firm switches from a dedicated to a flexible technology it begins to procure both inputs and, as a result, imposes some externality on its original supplier. The type of this externality depends on the degree of product differentiation. For example, let us consider a situation in which only producer 1 adopts flexible technology and producer 2 remains with dedicated production system. On the one hand, when products are complements higher demand for input Y should increase the demand for input X. Thus, the decision of producer 1 to enter the other part of the market creates positive externality for supplier 1. On the other hand, however, when products are substitutes, the demand for input Y increases at the expense of input X. This, in turn, imposes negative externality on supplier 1 which increases in γ. To see this, it is enough to show that

$$US_4^I - US_2^I \geq 0 \text{ and } US_4^I - US_3^I \geq 0 \tag{3.56}$$

and

$$US_4^I - US_1^I \geq 0 \tag{3.57}$$

where US_j^k represents total payoffs of suppliers given technology state j and sub-game equilibrium $k = I, M$ where I stands for independent suppliers and M for a single supplier. Condition (3.56) is given by

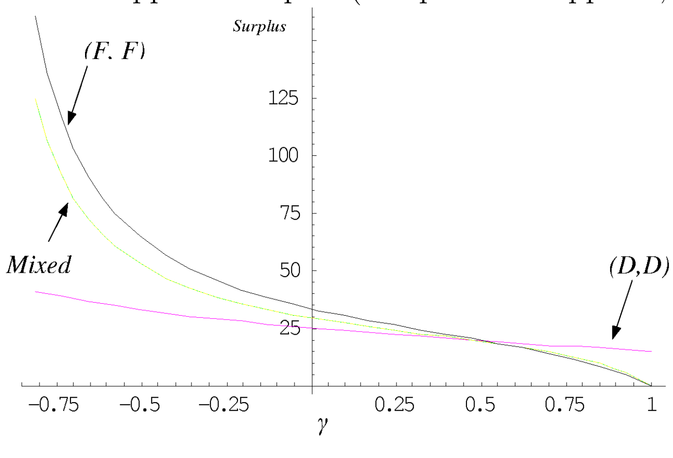
$$\frac{\alpha^2(128 - 256\gamma - 40\gamma^2 + 192^3 - 10\gamma^4 - 6\gamma^5 + 3\gamma^6 - 11\gamma^7)}{3(\gamma-2)^2(1+\gamma)(16-7\gamma^2)^2} \geq 0 \qquad (3.58)$$

and condition (3.57) can be expressed as

$$\frac{8\alpha^2(\gamma^4 - 4\gamma^3 + 6\gamma^2 - 10\gamma + 4)}{3(\gamma+1)(\gamma+2)(\gamma-4)^2(\gamma-2)^2} \geq 0. \qquad (3.59)$$

The effect of the degree of product differentiation on the payoffs of upstream firms can be expressed graphically. Figure 3.3 depicts suppliers' total surplus in all technology states as a function of γ. The surplus of upstream firms is at first the highest in (F,F) technology state and decreases in γ. When products become close substitutes, however, the negative externality posed by downstream firms increases the rivalry in the input market to such extent, that the payoff in (F,F) state becomes smaller than in (D,D) state. Consequently, (3.58) and (3.59) hold only for some values of γ. In this particular case, i.e. when $\alpha = 10$, (3.58) holds for $\gamma \in [-1, 0.6]$ and (3.59) is true for $\gamma \in [-1, 0.51]$. Then, the surplus of upstream firms is maximized when both downstream firms use D technology. In other words, suppliers prefer to maintain exclusive relations with producers.

Figure 3.3: Suppliers' surplus (independent suppliers, α=10)



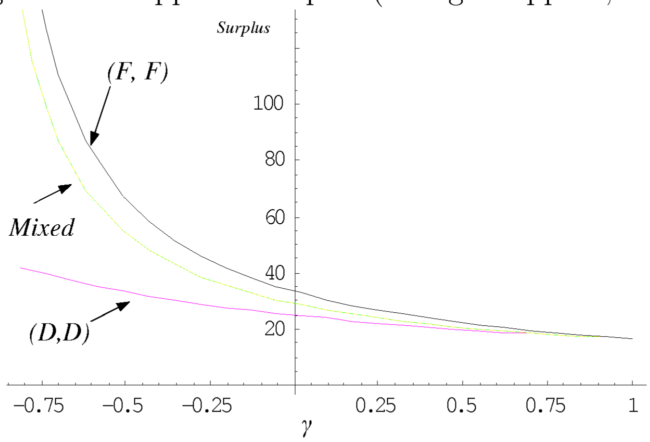
Let us now consider the case when there is one multi-product supplier.

From the previous analysis we know that the monopolistic supplier is always able to set prices that maximize monopolist's profit in all technology cases, i.e. $w_j^{XM} = w_j^{YM} = \frac{\alpha}{2}$. The possibility to set monopolistic prices for both inputs offsets the negative effects of increased intra-brand competition. Consequently, by selling both inputs to both downstream firms, a single supplier always benefits from a higher demand stimulated by the use of FPT. This leads to the following proposition:

> **Proposition 3:** *The profit of a multi-product monopolistic supplier is the highest when both manufacturers use FPT.*

Proof. See annex.

Figure 3.4: Suppliers' surplus (a single supplier, α=10)



Because the choice of technology made by downstream firms determines the final quantities of both products and, as a result, the demand for intermediate inputs, it has also an impact on the seller's final payoff. The total payoff of the upstream industry is however less sensitive to the degree of product differentiation and the technology choice when there is only a monopolistic supplier of both inputs, compared to the structure with two independent suppliers. Again, this can be illustrated graphically. Figure 3.4 shows that, although product substitutability is negatively related to the total payoff, a multi-product monopoly always maximizes its profit when each manufacturer is active in both parts of the market.

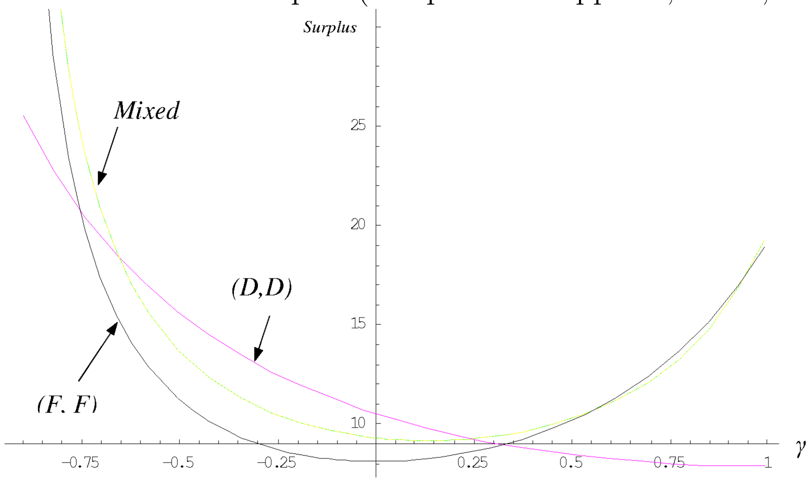
The above findings differs from the result obtained by Lin (1990). According to him, upstream firms prefer to choose exclusive dealing relations with downstream firms, which allow them to earn greater profits. In the current setting, however, provided that products are either complements or moderate substitutes, independent suppliers would benefit from downstream competition that has a direct impact on the quantities ordered by downstream firms. The total payoff of a monopolistic multiproduct supplier is always maximized when both manufacturers serve the two parts of the market.

Downstream firms

Intuitively, downstream companies forsake some profits when they are active in only one part of the market. By using D technology, each firm excludes itself from the other part of the market and reduces its final payoff. However, according to Röller et al. (1990), when both firms invest into flexible production technologies they reduce their profits due to increased rivalry in both parts of the market. Only one firm can benefit from producing both goods provided that the other firm supplies only one part of the market. Consequently, because producers collectively forsake profits when both of them adopt F technology, the technology choice takes a form of a Prisoners' Dilemma. Thus, the answer to the question of what technology downstream firm should choose to maximize its payoff might not be straightforward. Therefore, proceeding as before, in the following section I analyze the payoffs to the downstream manufacturers in all technology states and under both structures of the upstream industry. The main question here is which technology maximizes producers' profits.

First, I would like to discuss this question under the assumption that upstream industry has a competitive structure. Downstream firms might be inclined to adopt FPT in order to increase the product range. This, however, might have adverse impact on their final payoffs. Similarly as in the case of the input market, the competition and profits in the final product market will be influenced by the type of dependency between both products. To see this, let us turn to a graphical representation of producers' profits in all technology

Figure 3.5: Producers' surplus (independent suppliers, α=10, s=0.5)



states. Figure 3.5 illustrates producers' payoffs for $\alpha = 10$ and $s = 0.5$. It can be seen that producers' payoff is maximized in (F,F) technology state for a very limited range of γ. For most of the values of γ producers are better off when they remain with specialized equipment or when only one of them invests in FPT. Thus, an analysis of the manufacturers' surplus leads to the following Lemma:

Lemma 4: *If* $PS_j^I = \pi_{1,j}^{PI} + \pi_{2,j}^{PI}$ *is the total profit of the downstream industry in technology state* j*, given a competitive structure of the upstream industry* I*, and when* $\alpha = 10$ *and* $s = 0.5$ *then:*

a) $PS_1^I \geq PS_2^I = PS_3^I$ if $\gamma \in [-0.65, 0.24]$;

b) $PS_1^I \geq PS_4^I$ if $\gamma \in [-0.75, 0.32]$;

c) $PS_4^I \geq PS_2^I = PS_3^I$ if $\gamma \in [0.54, 0.95]$;

Proof. See annex.

Consequently, as it emerges from the above discussion, it is not always optimal from producers' stand point when both firms invest in flexible technologies.

Proceeding as above, let us now turn to the equilibrium outcomes that emerge under a monopolized upstream industry. Figure 3.6 illustrates the surplus of downstream firms for $\alpha = 10$ and $s = 0.5$. It can be seen that the negative effect of FPT on producers' profits is even stronger when inputs are procured from a multi-product monopolist. Nearly over the entire range of γ downstream firms maximize the total industry profit when they remain active in separated markets. An analysis of producers' payoffs leads to the following the following lemma:

> **Lemma 5:** *If $PS_j^M = \pi_{1,j}^{PM} + \pi_{2,j}^{PM}$ is the total profit of the downstream industry in technology state j, given a monopolistic structure of the upstream industry M, and when $\alpha = 10$ and $s = 0.5$ then:*
>
> a) $PS_1^M \geq PS_2^M = PS_3^M$ if $\gamma \in [-0.39, 1]$;
>
> b) $PS_1^M \geq PS_4^M$ if $\gamma \in [-0.55, 1]$;
>
> c) $PS_4^M \leq PS_2^M = PS_3^M$ if $\gamma \in [-1, 1]$.

Proof: See annex.

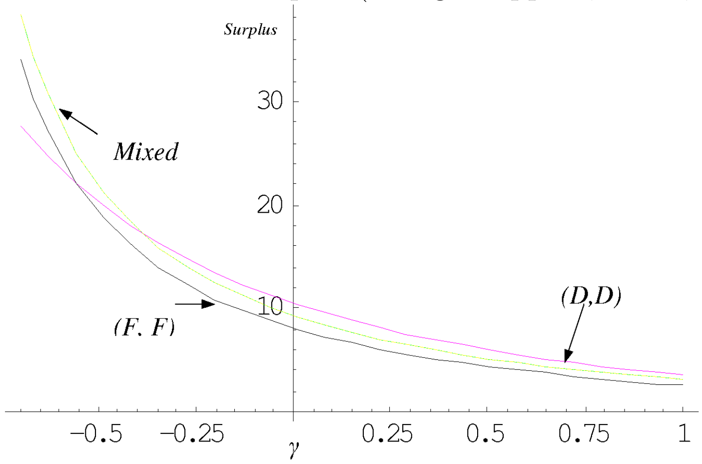
Lemma 5 implies that the payoffs of downstream firms decrease in γ and as the level of product complementarity decreases or products become stronger substitutes, companies forsake profits when they use FPT. This counters the intuition that firms can increase their payoffs by diversification. This leads to the following proposition:

> **Proposition 4:** *In equilibrium outcomes, the cumulative profit of downstream firms depends on the market size and the degree of product differentiation. The use of FPT by both producers never maximizes the total payoff of the downstream industry.*

Proof of the above proposition follows from the proof of Lemma 5 (see annex).

To a large extent these results are consistent with those by Röller et al. (1990). In particular, they confirm that, in most of the cases, an extension of the product range is detrimental to the producers' total payoff. Although the ability to produce many products leads to a significant increase in the profits

Figure 3.6: Producers' surplus (a single supplier, α=10, s=0.5)



of the producer switching from DPT to FPT, it happens at the expense of the other producer. Once both producers adopt FPT, the result is an immediate increase of intra-brand competition and the introduction of inter-brand rivalry. Eventually, both firms are worse off when they parallel choose flexible production technology. Obviously, this leads to a Prisoners' Dilemma.

3.5.3 Total welfare

This section discusses the effects of technology choice by downstream firms and consolidation of the upstream industry on total welfare. As usual, total welfare includes consumer surplus and total profits of both industries. Table 3.3 gives expressions for total welfare in all technology states and under both structures of the upstream industry.

Let us first consider the effect of technology choice by producers when there are two independent suppliers. Intuitively, FPT has a competition-increasing effect. Consequently, total welfare should be maximized when downstream firms choose F technology and supply both products. Then, from the social point of view, total welfare should be increased as the supply in the final market rises and prices decrease. To see this, let us turn to a graphical illustration. Figure 3.7 shows that the use of F technology by both firms is socially desirable indeed, but only to some extent. Surprisingly,

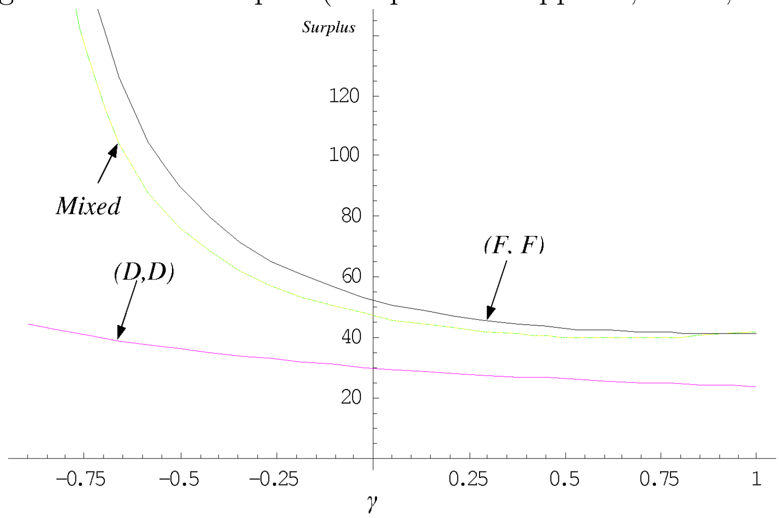
Table 3.3: Total welfare

Independent suppliers	
(D,D)	$\frac{4\alpha^2(\gamma+1)}{(\gamma-4)^2(\gamma+2)^2} - 2$
Mixed equilibrium	$\frac{\alpha^2(365\gamma^5-971\gamma^4-3016\gamma^3-6640\gamma^2+4352\gamma+9152)}{72(\gamma+1)(7\gamma^2-16)^2} - 2 - s$
(F,F)	$\frac{4\alpha^2(5-3\gamma)}{9(\gamma+1)(\gamma-2)^2} - 2(s+1)$
A single supplier	
(D,D)	$\frac{\alpha^2(3\gamma+7)}{4(\gamma+2)^2} - 2$
Mixed equilibrium	$\frac{\alpha^2(17\gamma+143)}{288(\gamma+1)} - 2 - s$
(F,F)	$\frac{5\alpha^2}{9(\gamma+1)} - 2(s+1)$

the presence of both firms in both parts of the market is desirable from the social welfare perspective only if $\gamma \leq 0.95$. When products are strong substitutes, asymmetric solution, in which one firm uses D technology and the other F technology, is preferred. In other words, if products are strong substitutes investing in FPT by both firms might be socially not efficient. This coincides with the previous conclusion regarding the possible technology outcomes under a competitive market structure. As illustrated in Figure 3.2, mixed equilibria could emerge if there were two independent suppliers in the region of γ close to 1. Thus, theoretically, there would be no concern of overinvestment in FPT. However, in such a case, downstream firms face a Prisoners' Dilemma, because, when both firms invest into flexible production technologies they reduce their profits due to increased rivalry in both parts of the market. Only one firm can benefit from producing both goods provided that the other firm supplies only one part of the market.

Let us now turn to a sub-game with a multi-product monopolistic supplier. As illustrated in figure 3.8, the negative effect of FPT on producers' payoff is even stronger when there is a monopolistic supplier of both inputs. Consequently, this indicates that when products are substitutable, investment into FPT might not be desired from the social welfare standpoint. The benefits of increased competition between closely substitutable products do not justify large investments into new production technologies. This result holds for both types of the upstream industry structure. Consequently, the

Figure 3.7: Total surplus (independent suppliers, α=10, s=0.5)

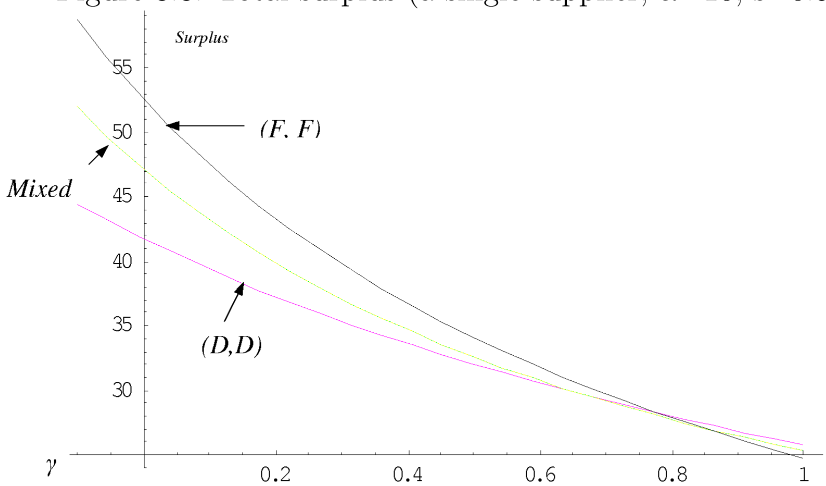


following can be stated:

Proposition 5: *When final products are sufficiently differentiated, the investment in FPT by both companies maximizes total welfare.*

Proof. See annex.

Figure 3.8: Total surplus (a single supplier, α=10, s=0.5)



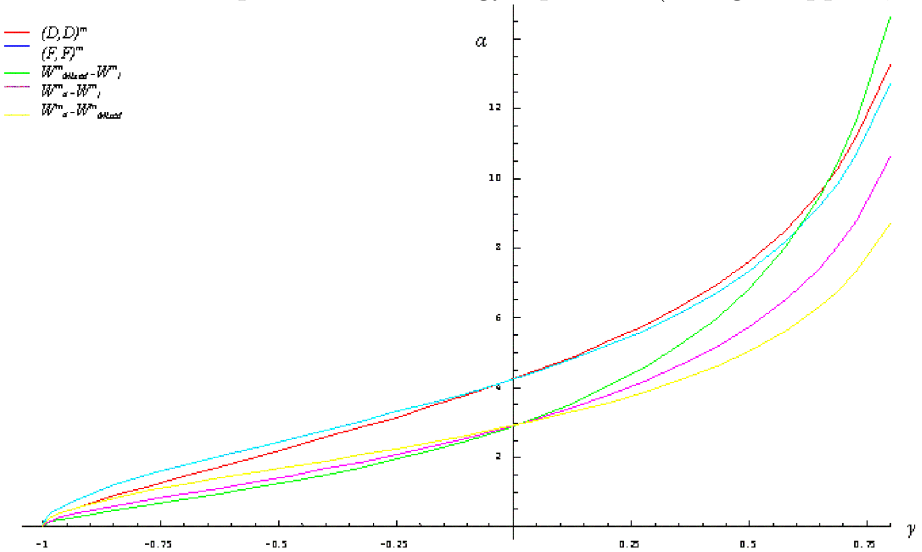
3.5.4 Total welfare and equilibrium technology choice

Taking stock of the implications of the technology choice and the structure of the upstream industry on the total surplus, it is worthwhile to ask to what extent equilibrium technology choice of downstream firms overlap with what is optimal from the total welfare point of view. Figure 3.9 illustrates all technology equilibria that emerge in a sub-game with merged suppliers together with the socially optimal outcomes in α and γ for a value of $s = 0.5$. Again, plotting the figure for various parameters of s showes that the results are not sensitive to the changes of parameter values. Regarding the equilibrium technology choice, the region below the red (D,D)^m curve includes the technology state in which both downstream firms remain with dedicated technology. The surface above the blue (F,F)^m curve shows the technology state in which both firms switch to flexible technology. The area between (D,D)^m and (F,F)^m includes mixed technology choices.

Regarding the socially optimal outcomes, the following curves illustrate the differences between the total welfare values under various technology states. In particular, the green line indicates the borderline for the condition that total welfare in a mixed outcome is greater than total welfare in (D,D) state, i.e. $W^m_{mixed} - W^m_1 \geq 0$. Similarly, the violet and orange lines show for what values of α and γ total welfare in (F,F) state is greater than in the (D,D) and the mixed state respectively, i.e. $W^m_4 - W^m_1 \geq 0$ and $W^m_4 - W^m_{Mixed} \geq 0$.

An analysis of the equilibrium and the socially optimal welfare regions leads to the conclusion that, for some range of α, the choice of manufacturers does not lead to a socially efficient outcome. In general, producers invest in flexible production technologies only when market is sufficiently large. For example, when products are complements, the socially optimal move from the (D,D) state to the mixed state lies above the green curve. In contrast, manufacturers choose the mixed equilibrium for the region of α and γ that lies between the red and blue curves. Similarly, the equilibrium move from a mixed case to the (F,F) outcome lies above the blue curve, although the socially optimal choice of FPT by both manufacturers would be for much smaller value of α, i.e. above the orange curve.

Figure 3.9: Total surplus and technology equilibria (a single supplier, s=0.5)



Thus, it can be seen that firms invest into FPT for much larger values of α (above the blue line) than socially optimal (above the violet curve). In short, the socially inefficient outcomes emerge for values of α that lie:

- between the green and red lines when products are complements, and
- between the violet and blue lines for all types of products.

An additional analysis of the manufacturers' choice and the socially optimal outcome under a competitive structure of the upstream industry revealed that the type of the upstream industry structure does not move producers to an outcome, which would be desirable from the total welfare point of view. Consequently, for some intermediate size of market there is a divergence between the manufacturers' incentives and socially optimal outcome. The above results can be summarized in the following proposition:

> **Proposition 6:** *There is a set of α for which the manufacturers' choice does not lead to a socially efficient outcome with respect to the technology choice. In general, manufacturers choose to invest in FPT in much larger markets than it would be desirable from the social point of view.*

Proof. See annex.

3.6 Conclusions

The starting point of the discussion presented in this chapter was the argument of Milgrom and Roberts (1990) that the adoption of FPT accompanied by complementary changes in firms' strategy and organization change modern manufacturing and service industries. The current work aimed at illustrating these transformations and analyzing manufacturers' decisions regarding the choice of production technologies in the context of vertical relations. By using a model of two supply chains, I show that the effects of the adoption of flexible production equipment on firms' profits and welfare is far from straightforward.

First, although profitable for an individual producer, the adoption of technologies increasing product variety across the entire industry erodes producers' payoffs. Despite the fact that, in some cases, mixed technology states in which one firm uses flexible and the other dedicated technology can be justified, downstream firms are better off when they remain with specialized equipment and produce only one product. In particular, when products are close substitutes, any benefits stemming from an increased product variety do not justify investments into flexible technology by all firms in the industry. As a result, producers end up in a Prisoners' Dilemma.

Second, the introduction of flexible technologies on the payoff of the upstream industry is not straightforward as well. Contrary to some previous findings, I show that, regardless of the upstream market structure, the upstream industry is always better off when both downstream firms use FPT. In particular, a multiproduct monopolistic suppliers benefits from an increased demand for both inputs. However, these benefits diminish as products become close substitutes.

Third, regarding the structure of the upstream industry, suppliers maximize their profits when they merge in all cases, i.e. irrespective of the degree of product differentiation. Consequently, along consumers, a multiproduct monopolistic supplier always benefits from manufacturers' move towards new technologies and greater product variety.

Finally, the decisions made by producers with respect to the technology choice are not always efficient from the social welfare point of view. In particular, firms invest into new technologies only when markets are sufficiently large.

One of the limitations of the current work is that the design of the model influences the results. Consequently, it might be worthwhile to check their robustness under different frameworks. One way to extend the current structure would be an introduction of a bargaining game between upstream and downstream firms over two-part contracts, instead of a price maximization and Cournot competition. Another way is to relax the assumption with respect to the number of firms. Nevertheless, despite its simple framework, the model can be applied to a number of realistic situations. Furthermore, the results obtained here seem to reflex anecdotal and empirical evidence on the technology-driven impacts on vertical relations and firms' strategies regarding product variety as well.

Concluding, the impacts of value chain transformation and the diffusion of FPT might go far beyond the increased product variety offered by firms. Other changes that can be triggered by the technological transition might include intensified competition in product and input markets. Eventually, the changes might have adverse effect on firms that seek to escape competition and increase profitability by the adoption of new technologies.

3.7 Annex

3.7.1 Tables

Table 3.4: Equilibrium expressions for all technology states (independent suppliers)

Upstream	(D,D)	(F,D)*	(F,F)
w_j^{XI*}	$\frac{\alpha(\gamma-2)}{(\gamma-4)}$	$\frac{\alpha(\gamma^3-5\gamma^2-4\gamma-8)}{16-7\gamma^2}$	$\frac{\alpha(\gamma-1)}{(\gamma-2)}$
w_j^{YI*}	$\frac{\alpha(\gamma-2)}{(\gamma-4)}$	$\frac{\alpha(5\gamma^2+3\gamma-8)}{7\gamma^2-16}$	$\frac{\alpha(\gamma-1)}{(\gamma-2)}$
$\pi_{1,j}^{U*}$	$\frac{2\alpha^2(2-\gamma)}{(\gamma+2)(\gamma-4)^2}$	$\frac{-\alpha(\gamma^5-9\gamma^4+8\gamma^3+64\gamma^2-64)}{2(\gamma+1)(7\gamma^2-16)^2}$	$\frac{2\alpha^2(1-\gamma)}{3(\gamma-2)^2(\gamma+1)}$
$\pi_{2,j}^{U*}$	$\frac{2\alpha^2(2-\gamma)}{(\gamma+2)(\gamma-4)^2}$	$\frac{\alpha(25\gamma^5+65\gamma^4-116\gamma^3-284\gamma^2+64\gamma+256)}{6(\gamma+1)(7\gamma^2-16)^2}$	$\frac{2\alpha^2(1-\gamma)}{3(\gamma-2)^2(\gamma+1)}$
Downstream			
$x_{1,j}^{I*}, x_{2,j}^{I*}$	$\frac{2\alpha}{(\gamma+2)(4-\gamma)}, 0$	$\frac{\alpha(\gamma^2-4\gamma-8)}{2(\gamma+1)(7\gamma^2-16)}, 0$	$\frac{\alpha}{3(2-\gamma)(\gamma+1)}, \frac{\alpha}{3(2-\gamma)(\gamma+1)}$
$y_{1,j}^{I*}, y_{2,j}^{I*}$	$0, \frac{2\alpha}{(\gamma+2)(4-\gamma)}$	$\frac{\alpha(\gamma^3+10\gamma^2+2\gamma-16)}{6(\gamma+1)(7\gamma^2-16)}, \frac{\alpha(2\gamma^2-3\gamma-8)}{3(7\gamma^2-16)}$	$\frac{\alpha}{3(2-\gamma)(\gamma+1)}, \frac{\alpha}{3(2-\gamma)(\gamma+1)}$
p_j^{XI*}	$\frac{\alpha(\gamma^2-6)}{(\gamma-4)(\gamma+2)}$	$\frac{\alpha(5\gamma^3-39\gamma^2-20\gamma+72)}{6(16-7\gamma^2)}$	$\frac{\alpha(3\gamma-4)}{3(\gamma-2)}$
p_j^{YI*}	$\frac{\alpha(\gamma^2-6)}{(\gamma-4)(\gamma+2)}$	$\frac{\alpha(17\gamma^2+6\gamma-32)}{3(7\gamma^2-16)}$	$\frac{\alpha(3\gamma-4)}{3(\gamma-2)}$
$\pi_{1,j}^{PI*}$	$\frac{4\alpha^2}{(\gamma+2)^2(\gamma-4)^2} - 1$	$\frac{\alpha^2(\gamma^3+7\gamma^2-28\gamma-52)}{36(\gamma+1)(7\gamma^2-16)} - 1 - s$	$\frac{2\alpha^2}{9(\gamma-2)^2(\gamma+1)} - 1 - s$
$\pi_{2,j}^{PI*}$	$\frac{4\alpha^2}{(\gamma+2)^2(\gamma-4)^2} - 1$	$\frac{\alpha^2(2\gamma^2-3\gamma-8)^2}{9(7\gamma^2-16)^2} - 1$	$\frac{2\alpha^2}{9(\gamma-2)^2(\gamma+1)} - 1 - s$
* In (D,F) equilibrium the reverse is true			

Table 3.5: Equilibrium expressions for all technology states (a single supplier)

Upstream	(D,D)	(F,D)*	(F,F)
w_j^{XM*}, w_j^{YM*}	$\frac{\alpha}{2}$	$\frac{\alpha}{2}$	$\frac{\alpha}{2}$
π_j^{M*}	$\frac{\alpha^2}{2(\gamma+2)}$	$\frac{\alpha^2(\gamma+7)}{24(\gamma+1)}$	$\frac{\alpha^2}{3(\gamma+1)}$
Downstream			
$x_{1,j}^{M*}, x_{2,j}^{M*}$	$\frac{2\alpha}{2(\gamma+2)}, 0$	$\frac{\alpha}{4(\gamma+1)}, 0$	$\frac{\alpha}{6(\gamma+1)}, \frac{\alpha}{6(\gamma+1)}$
$y_{1,j}^{M*}, y_{2,j}^{M*}$	$0, \frac{2\alpha}{2(\gamma+2)}$	$\frac{\alpha(2-\gamma)}{12(\gamma+1)}, \frac{\alpha}{6}$	$\frac{\alpha}{6(\gamma+1)}, \frac{\alpha}{6(\gamma+1)}$
p_j^{XM*}	$\frac{\alpha(\gamma+3)}{2(\gamma+2)}$	$\frac{\alpha(9-\gamma)}{12}$	$\frac{2\alpha}{3}$
p_j^{YM*}	$\frac{\alpha(\gamma+3)}{2(\gamma+2)}$	$\frac{2\alpha}{3}$	$\frac{2\alpha}{3}$
$\pi_{1,j}^{PM*}$	$\frac{\alpha^2}{4(\gamma+2)^2} - 1$	$\frac{\alpha^2(13-5\gamma)}{144(\gamma+1)} - 1 - s$	$\frac{\alpha^2}{18(\gamma+1)} - 1 - s$
$\pi_{2,j}^{PM*}$	$\frac{\alpha^2}{4(\gamma+2)^2} - 1$	$\frac{\alpha^2}{36} - 1$	$\frac{\alpha^2}{18(\gamma+1)} - 1 - s$
* In (D,F) equilibrium the reverse is true			

3.7.2 Proofs

Proof of Lemma 3:

a) Providing that suppliers are independent, consumer surplus is maximized in (F,F) technology state when the following conditions are satisfied. First, consumer surplus in mixed technology state must be lower than consumer surplus in (F,F) technology outcome. This is true when

$$CS_4^I - CS_2^I \geq 0 \text{ and } CS_4^I - CS_3^I \geq 0 \tag{3.60}$$

Second, consumer surplus in mixed equilibria must be higher than consumer surplus in (D,D) technology state. This is true when

$$CS_2^I - CS_1^I \geq 0 \text{ and } CS_3^I - CS_1^I \geq 0 \tag{3.61}$$

Condition (3.60) can be expressed in the following way:

$$\frac{\alpha^2(1792 - 768\gamma - 896\gamma^2 + 32\gamma^3 - 596\gamma^4 + 224\gamma^5 + 267\gamma^6 - 55\gamma^7)}{72(\gamma+1)(\gamma-2)^2(7\gamma^2-16)^2} \geq 0 \tag{3.62}$$

Similarly, condition (3.61) can be written as

$$\frac{\alpha^2(28672 + 18432\gamma + 17664\gamma^2 + 55040\gamma^3 + 23712\gamma^4 - 16128\gamma^5 - 9436\gamma^6 - 1104\gamma^7 - 267\gamma^8 + 55\gamma^9)}{72(\gamma+1)(\gamma-4)^2(\gamma+2)^2(7\gamma^2-16)^2} \geq 0 \tag{3.63}$$

It can be shown graphically that both conditions are fulfilled for the relevant rage of $\gamma \in [-1, 1]$ and $\alpha > 0$.

Q.E.D.

b) Proceeding as above, it is enough to show that two conditions are satisfied. First, consumer surplus in mixed equilibria must be lower than consumer surplus in (F,F) equilibrium. This is true when

$$CS_4^M - CS_2^M \geq 0 \text{ and } CS_4^M - CS_3^M \geq 0 \tag{3.64}$$

Second, consumer surplus in mixed equilibria must be higher than consumer surplus in (D,D) equilibrium. This is true when

$$CS_2^M - CS_1^M \geq 0 \text{ and } CS_3^M - CS_1^M \geq 0 \tag{3.65}$$

Condition (3.64) can be expressed as:

$$\frac{7\alpha^2(1-\gamma)}{288(\gamma+1)} \geq 0 \tag{3.66}$$

Similarly, condition (3.65) can be written as

$$\frac{\alpha^2(7\gamma^3 - 19\gamma^2 - 16\gamma + 28)}{288(\gamma+1)(\gamma+2)^2} \geq 0 \tag{3.67}$$

Both expressions, (3.66) and (3.67), are fulfilled for all values of γ.

Q.E.D.

c) and d) These results hold when the difference between consumer surplus in (F,F) with independent suppliers and consumer surplus in the same technology state but with a monopolistic input market is positive (negative) if products are substitutes (complements). This holds when

$$CS_4^I - CS_4^M \geq 0 \tag{3.68}$$

or

$$\frac{\alpha^2\gamma(4-\gamma)}{9(\gamma-2)^2(1+\gamma)} \geq 0 \tag{3.69}$$

for $0 \leq \gamma \leq 1$ and

$$CS_4^I - CS_4^M < 0 \tag{3.70}$$

or

$$\frac{\alpha^2\gamma(4-\gamma)}{9(\gamma-2)^2(1+\gamma)} < 0 \tag{3.71}$$

for $0 \leq \gamma \leq 1$. It is straightforward to see that the sign of both inequalities depends on the sign of γ and that both conditions are satisfied for relevant types of products.

Q.E.D.

Proof of Lemma 4:

a) To prove this result, it needs be to shown that

$$PS_1^I - PS_2^I \geq 0 \text{ and } PS_1^I - PS_3^I \geq 0 \tag{3.72}$$

hold for some value of γ. PS_j^I represents total payoffs of downstream producers given technology state j and upstream market structure I. Condition (3.72) is equivalent to

$$s - \frac{\alpha^2(23\gamma^9 - 75\gamma^8 - 696\gamma^7 + 1564\gamma^6 - 5472\gamma^5 - 22272\gamma^4 + 14848\gamma^3 + 56064\gamma^2 + 18432\gamma - 4096)}{36(\gamma+1)(\gamma-4)^2(\gamma+2)^2(7\gamma^2-16)^2} \geq 0 \tag{3.73}$$

and it can be shown graphically that it holds for some value of α and s. For example, if we set $\alpha = 10$ and $s = 0.5$ then $PS_1^I \geq PS_2^I = PS_3^I$ if $\gamma \in [-0.65, 0.24]$.

Q.E.D.

b) To prove this result, it needs be to shown that

$$PS_1^I - PS_4^I \geq 0. \tag{3.74}$$

This can be expressed as

$$2s - \frac{4\alpha^2(\gamma^4 - 22\gamma^3 + 42\gamma^2 + 32\gamma - 8)}{9(\gamma+1)(\gamma-2)^2(\gamma^2-2\gamma-8)^2} \geq 0 \tag{3.75}$$

Again, it can be shown that if we set $\alpha = 10$ and $s = 0.5$, (3.75) holds for $\gamma \in [-0.75, 0.32]$.

Q.E.D.

c) To prove this result, it needs be to shown that

$$PS_4^I - PS_2^I \geq 0 \text{ and } PS_4^I - PS_3^I \geq 0 \tag{3.76}$$

hold for some γ. This can be expressed as

$$-\frac{\alpha^2(23\gamma^7 - 75\gamma^6 - 328\gamma^5 + 316\gamma^4 + 992\gamma^3 - 416\gamma^2 - 768\gamma + 256)}{36(1+\gamma)(\gamma-2)^2(7\gamma^2-16)^2} - s \geq 0 \tag{3.77}$$

Again, by setting $\alpha = 10$ and $s = 0.5$ it can be shown graphically that it holds for $\gamma \in [0.54, 0.95]$.

Q.E.D.

Proof of Lemma 5:

a) This result if true when

$$PS_1^M - PS_2^M \geq 0 \text{ and } PS_1^M - PS_3^M \geq 0 \tag{3.78}$$

hold for some values of γ. Inequality (3.78) can be written as

$$\frac{\alpha^2(\gamma^3 - 13\gamma^2 + 8\gamma + 4)}{144(1+\gamma)(\gamma-2)^2} + s \geq 0 \tag{3.79}$$

This holds for positive α and $s \neq 0$. For example, if $\alpha = 10$ and $s = 0.5$ the above expression is fulfilled when $\gamma \in [-0.39, 1]$.

Q.E.D.

b) This result if true when

$$PS_1^M - PS_4^M \geq 0 \tag{3.80}$$

is true for some positive values of γ. Condition (3.80) can be written as

$$2s - \frac{\alpha^2(2\gamma^2 - \gamma - 1)}{18(\gamma+1)(\gamma+2)^2} \geq 0 \tag{3.81}$$

Again, it can be shown that for positive α and $s \neq 0$, the above condition is fulfilled when $\gamma \in [-0.55, 1]$.

Q.E.D.

c) This result if true when

$$PS_4^M - PS_2^M \leq 0 \text{ and } PS_4^M - PS_3^M \leq 0 \tag{3.82}$$

is true for some positive values of γ. Condition (3.80) can be written as

$$\frac{\alpha^2(\gamma-1)}{144(\gamma+1)} - s \leq 0 \tag{3.83}$$

Again, it can be shown graphically that for positive α and $s \neq 0$, the above condition is fulfilled for all relevant values of γ.

Q.E.D.

Proof of Proposition 3. In order to prove this proposition, it is enough to show that

$$US_4^M - US_2^M \geq 0 \text{ and } US_4^M - US_3^M \geq 0 \tag{3.84}$$

and

$$US_4^M - US_1^M \geq 0 \tag{3.85}$$

Inequality (3.84) is given by

$$\frac{\alpha^2(1-\gamma)}{24(1+\gamma)} \geq 0 \tag{3.86}$$

and condition (3.85) can be written as

$$\frac{\alpha^2(1-\gamma)}{6(\gamma^2+3\gamma+2)} \geq 0 \tag{3.87}$$

It is straightforward that both are positive for all values of γ.

Q.E.D.

Proof of Proposition 5. In order to prove this proposition, it is necessary to show that for some values of γ close to 1 total welfare is not maximized when both producers are active in both markets. Let us first start with the case in which there are two suppliers. Then the following conditions must be met:

$$W_4^I - W_2^I \geq 0 \text{ and } W_4^I - W_3^I \geq 0 \tag{3.88}$$

and

$$W_4^I - W_1^I \geq 0 \tag{3.89}$$

Where W_j^k represents total welfare given technology state j and sub-game equilibrium $k = I, M$ where I stands for independent suppliers and M for a single supplier. Condition (3.88) is given by

$$\frac{\alpha^2(4352 - 5376\gamma - 1024\gamma^2 + 2656\gamma^3 - 1468\gamma^4 + 736\gamma^5 + 489\gamma^6 - 365\gamma^7)}{72(1+\gamma)(32 - 16\gamma - 14\gamma^2 + 7\gamma^3)^2} - s \geq 0 \tag{3.90}$$

and (3.89) can be expressed as

$$\frac{4\alpha^2(2168-2208\gamma-978\gamma^2+238\gamma^3-273\gamma^4+246\gamma^5-67\gamma^6 6\gamma^7)}{9(\gamma-4)^4(1+\gamma)(\gamma^2-4)^2}-2s\geq 0 \tag{3.91}$$

It can be shown graphically that for positive α and $s\neq 0$. both conditions are fulfilled. For example, if $\alpha=10$ and $s=0.5$ condition (3.90) is satisfied for $\gamma\in[-1,0.95]$, i.e. except when products are strong substitutes. Condition (3.91) holds for all values of γ.

Second, considering the case in which there is a multi-product monopolistic supplier, it is necessary to show that

$$W_4^M-W_2^M\leq 0 \text{ and } W_4^M-W_3^M\leq 0 \tag{3.92}$$

and

$$W_4^M-W_1^M\leq 0 \tag{3.93}$$

hold for some values of γ. Condition (3.92) can be expressed as

$$\frac{17\alpha^2(1-\gamma)}{288(1+\gamma)}-s\leq 0 \tag{3.94}$$

Similarly, condition (3.93) is equivalent to

$$\frac{\alpha^2(17-10\gamma-7\gamma^2)}{36(\gamma+2)^2(1+\gamma)}-2s\leq 0 \tag{3.95}$$

Proceeding as above, it can be illustrated that both expressions are fulfilled for positive α and $s\neq 0$. For example, if $\alpha=10$ and $s=0.5$, (3.94) holds for $\gamma\in[0.84,1]$ and (3.95) holds when $\gamma\in[0.78,1]$.

Q.E.D.

Proof of Proposition 6. To prove this proposition, it is necessary to show that, for some values of α, the equilibrium regions of technology choice under a monopolized upstream market do not overlap with the socially efficient outcomes. Thus, let us start with complementary products and consider the case of the move from the (D,D) to the mixed technology state.

It can be shown that the condition for a socially efficient adoption of FPT by one producer needs to satisfy the following inequality:

$$W_2^M - W_1^M \geq 0 \text{ and } W_3^M - W_1^M \geq 0, \tag{3.96}$$

which is equivalent to

$$\alpha \geq \sqrt{\frac{s}{f_{DD2Mix}^M(\gamma)}}, \tag{3.97}$$

where

$$f_{DD2Mix}^M(\gamma) = \frac{(68 - 80\gamma - 5\gamma^2 + 17\gamma^3)}{288(\gamma+2)^2(1+\gamma)}. \tag{3.98}$$

From Proposition 1 in section 3.4, we know that there is a mixed equilibrium for complementary products when $\sqrt{\frac{s}{f_{DD}^M(\gamma)}} \leq \alpha < \sqrt{\frac{s}{f_{FF}^M(\gamma)}}$. Thus, to show that the choice of manufacturers does not lead to a socially optimal outcome it needs to be proved that the following condition is met:

$$f_{DD2Mix}^M(\gamma) - f_{DD}^M(\gamma) \geq 0, \tag{3.99}$$

which can be expressed as

$$\frac{(3\gamma^2 - 5\gamma + 2)}{32(\gamma+2)(1+\gamma)} \geq 0. \tag{3.100}$$

It can be seen that for complementary products the above condition is always satisfied. In other words, there are some values of α in which mixed equilibria would be socially efficient, but they do not exist, as companies consider such markets as too small.

Second, considering further the case of complementary products, it needs to be shown that, for some values of α, companies do not move from mixed technology equilibria to the (F,F) technology state, although it would be socially desirable. The adoption of FPT by both companies versus only one is socially efficient when:

$$W_4^M - W_2^M \geq 0 \text{ and } W_4^M - W_3^M \geq 0, \tag{3.101}$$

which is equivalent to

$$\alpha \geq \sqrt{\frac{s}{f^M_{Mix2FF}(\gamma)}}, \tag{3.102}$$

where

$$f^M_{Mix2FF}(\gamma) = \frac{17(1-\gamma)}{288(1+\gamma)}. \tag{3.103}$$

From Proposition 1 in section 3.4, we know that there is a (F,F) equilibrium for complementary products when $\alpha \geq \sqrt{\frac{s}{f^M_{FF}(\gamma)}}$. Thus, if the choice of manufacturers does not lead to a socially optimal outcome the following condition must hold:

$$f^M_{Mix2FF}(\gamma) - f^M_{FF}(\gamma) \geq 0, \tag{3.104}$$

which can be expressed as

$$\frac{1-\gamma}{32(1+\gamma)} \geq 0. \tag{3.105}$$

Again, it is straightforward that, for complementary products, the above condition is always satisfied.

Lastly, it needs to be shown that, for some values of α, companies do not move from the (D,D) equilibrium to the (F,F) technology state, although it would be socially desirable. The adoption of FPT by both companies versus the (D,D) state is socially efficient when:

$$W^M_4 - W^M_1 \geq 0, \tag{3.106}$$

which is equivalent to

$$\alpha \geq \sqrt{\frac{s}{f^M_{DD2FF}(\gamma)}}, \tag{3.107}$$

where

$$f^M_{DD2FF}(\gamma) = \frac{17-10\gamma-7\gamma^2}{36(1+\gamma)(2+\gamma)^2}. \tag{3.108}$$

From Proposition 1 in section 3.4, we know that both companies choose to invest into FPT when $\alpha \geq \sqrt{\frac{s}{f^M_{FF}(\gamma)}}$. Thus, to show that the choice of manufacturers does not lead to a socially optimal outcome it needs to be proved that the following condition is met:

$$f^M_{DD2FF}(\gamma) - f^M_{FF}(\gamma) \geq 0, \tag{3.109}$$

which can be expressed as

$$\frac{\gamma^3 - 4\gamma^2 - 10\gamma + 13}{36(1+\gamma)(2+\gamma)^2} \geq 0. \tag{3.110}$$

Again, it is easy to see that the above condition is always satisfied. Concluding, taking into account that conditions (3.100), (3.105) and (3.110) are satisfied for the relevant range of γ, it has been proved that for some intermediary value of α, the decisions of downstream firms deliver socially inefficient outcomes. Q.E.D.

Chapter 4

The impact of e-procurement on the number of suppliers

4.1 Introduction

Information and communication technologies (ICT) such as electronic procurement have been expected to have considerable impact on the supplier-buyer relations and the organization of economic activity since the beginning of their rapid proliferation. The first prediction based on the transaction cost theory (Coase (1937)) said that the use of electronic transaction technologies and practices would result in more market-based relations between firms (Malone et al. (1987)). The opponents argued, however, that relationship-specific investments, asset specificity and product complexity effectively prohibit companies from engaging in pure market transactions. As a result, firms will continue to internalize business activities to overcome market deficiencies (Bakos and Brynjolfsson (1993) and (1993a)). Following the Williamson's definition of hybrid organizational form (Williamson (1991)), it was argued that a new organizational form would emerge that would combine elements of both markets and hierarchies. The alternative paradigm was labelled as move to the middle.

So far, however, there is still a lack of a consistent theoretical framework specific to the supplier-buyer relations and electronic networks and there are only few attempts to design a framework for understanding the nature of supplier-buyer relations as a consequence of the use of internet transaction applications (e.g. Bakos and Brynjolfsson (1993 and 1993a), Jap and Mohr (2002), Chen and Paulraj (2004) and Wagner and Essig (2006)). Most of the approaches generalize the concept of ICT and do not account for the fact that various ICT applications are adopted to serve different purposes and, therefore, have diverse effects on company conduct. Similar, empirical studies suffer from the inadequate and generalized conceptualization of ICT and measurement of the impact of electronic transaction applications on the organization of economic activity and supplier-buyer relations (e.g. Steinfield et al. (1995) and Min et al. (2001)). Furthermore, a number of studies is based on anecdotal evidence rather than on a large sample of data (e.g. Roberts et al. (1998) and McIvor et al. (2000)). Consequently, empirical attempts yielded inconclusive results as well (e.g. Steinfield et al. (1995), Chan et al. (1999) and Forman et al. (2005)).

Aiming to fill the gap in understanding the relationship between electronic procurement and its impact on the organization of vertical relations, I analyze the impact of electronic procurement on the number of suppliers. The main questions of interest here is whether *the brokerage effect* of electronic procurement enables firms to increase the number of suppliers, or whether *the coordination effect* of this application reinforces the relationships between firms and leads to the creation of hybrid organization forms (Malone et al. (1987)). In order to understand these interactions, I review the main conclusions from the relevant literature and illustrate the interactions between the technology deployed in the context of vertical relations and its impact on the supplier number with a simple conceptual model. Apart from the commonly recognized effects of electronic procurement, such as lower transaction and coordination cost (Malone et al. (1987)), I postulate that the impact of electronic procurement on supplier competition is another element which shapes firms' sourcing strategies and the supplier-buyer relations. Taking this as a starting point, I formulate hypotheses with respect to the effects of electronic procurement technology and practices on the sourcing strategy as a function of transaction cost and asset specificity. I test these hypotheses by using a multinominal logit model of a supplier number change. In the analysis, I use data on the ICT use and its impact collected within the e-Business W@tch 2006 survey. This unique data set enables me to include variables controlling for the impact of ICT on transaction costs, asset specificity, transaction economies of scale and geographical proximity to supplier and basic characteristics of the surveyed firms.

The results reveal that, in general, electronic procurement leads to an increase in the number of suppliers. Thus, these observations contradict the predictions that ICT leads to a dominance of network-like organizational forms and supports the view that ICT increases the attractiveness of markets as an organizational form of economic activity (Clemons et al. (1993)). The analysis provides evidence that the motivations to move to the market can be explained by the positive impact of ICT on transaction cost and the transaction economies of scale. However, despite a positive impact of electronic procurement on the cost of procurement, some firms choose to decrease the number of their suppliers. In particular, firm size and age seem to be important determinants of what are the implications of electronic procurement on the relationships with suppliers and the number of sourcing options. This is consistent with the risk-augmented transaction cost perspective (Kauffman and Mohtadi (2004)), which predicts that the risk preferences with respect to supply certainty shape companies decision on the choice of the procurement mode and the relationship with suppliers. As a result, large firms are more likely to adopt costlier solutions, as they offer them more certain-to-deliver value. In contrast, smaller firms tend to choose applications that minimize transaction costs, on the one hand, and whose use entails greater supply uncertainties, on the other hand.

The implications of these results can be summarized as follows. First, electronic procurement combined with changes in sourcing strategy leads to a reduction of transaction costs and, as a result, opens up new possibilities in terms of how business activities can be organized or how to structure competition in upstream markets. This is of course of great importance for companies whose customers implement electronic procurement, because it can be used to intensify competition in their market. As a result, it will change their environment and force them to look for new ways of maintaining profitability. Second, the example of electronic procurement shows that the impact of ICT on the way firms organize their activities is far from straightforward. Consequently, any technology implementation project should take into account the interactions between technology, organization and its environment. Similarly, the current analysis shows that empirical studies that generalize ICT by proxing the technology use by ICT expenditures or ICT endowment neglect the fact that various applications are adopted for different strategic reasons, in different contexts and within different environments (for literature review see, for example, Forman and Goldfarb (2005)). Consequently, they have different implications for companies' organization and performance. ICT constitutes of heterogeneous applications and therefore one should expect heterogeneous implications of different applications on firm activities and performance.

The approach taken in this study exhibits considerable differences to other studies aiming at answering the question of how electronic procurement influences the number of sourcing options. In particular, I focus here only on one ICT application and its effect on one strategic variable of the supplier-buyer relations. Furthermore, by using survey data, I make use of over 14,000 representative observations of ICT use and its impact across a number of industries. Despite clear advantages over the case-study methodology, this approach has some drawbacks as well. Most importantly, it does not allow to distinguish between various types of applications, e.g. between open and closed networks, and the transaction types, although both of them might have important implications for companies' sourcing decisions. Nevertheless, as far as I am aware, the current analysis is the first approach to study the effect of electronic procurement on the supplier-buyer relationships by using a large number of observations across various industries.

The remaining part of the chapter is organized as follows: Section 4.2 reviews the discussion on the impact of ICT on firm boundaries and sourcing strategy and establishes a conceptual foundation for further empirical examination. Section 4.3 describes the data used in the study and presents some descriptive statistics illustrating companies' choices regarding the optimal number of suppliers as a function of the electronic procurement deployment. Section 4.4 presents the findings and discusses the limitations of this analysis. Section 4.5 concludes.

4.2 E-procurement and supplier-buyer relations

4.2.1 Literature review

Transaction cost theory predicts that decreasing costs of search, evaluation and monitoring of suppliers should lead to a shift toward markets as a form of organizing economic activity (Coase (1937), Williamson (1985)). Consequently, the expectations regarding the potential of ICT as technologies introducing innovative ways of doing business, re-shaping firm boundaries and changing the constellations of value chains were enormous (e.g. Johnston et al. (1988), Milgrom et al. (1990), Fulk et al. (1995)). Among others, electronic procurement, seen as a technology driving transaction cost down, was said to increase the attractiveness of markets at the cost of hierarchies (Malone et al. (1987), Lucking-Reiley et al. (2001)). The prophecy of friction-free markets spurred a vivid discussion on the impact of electronic procurement on the organization of economic activity and supplier-buyer relations. Pointing to the fact that inter-firm transactions do not depend only on the cost of searching and evaluating new suppliers, critics deemed the expectations of the move to the market paradigm as premature. The most important elements preventing companies from engaging into pure market transactions include relationship specific investments, asset specificity and market complexity (Klein et al. (1978), Williamson (1979)). Thus, in order to overcome the problems arising from market deficiencies, companies internalize transactions. Bakos and Brynjolfsson (1993, 1993a) argue that companies implementing ICT in general and supplier-buyer networks in particular would benefit from reduced costs of information exchange and processing, but they would not immediately move to markets. Instead, when relationship investments are indispensable or specific assets are procured firms will create networks in which suppliers and buyers form closed business relationships facilitated by ICT (Thompson (2004)). The paradigm explaining the role of ICT in supporting the transformation towards a hybrid mode was named a move to the middle (Johnston et al. (1988a), Clemons et al. (1993, 1994), Hennart (1993)).

One of the aspects of the electronic transaction applications' impact on organizing economic activity is the choice of the optimal number of suppliers. According to the above discussion, it is likely that sourcing strategy changes with electronic procurement in place. It is thus necessary to ask whether the introduction of such applications leads to cooperation with a larger number of suppliers, or to a close integration with few partners. The former is suggested by the fact that a technology lowering searching and filtering costs gives firms incentives to increase the number of sourcing options in order to intensify the competition between suppliers and reduce suppliers' bargaining position (Mukhopadhyay et al. (2002)). Thus, electronic procurement indirectly increases upstream competition and lowers input prices. The price effect, however, is not the only aspect a firm takes into account while defining its sourcing strategy. The benefits of price effect have to be weighted against coordination costs and supply risk, which increase with the number of suppliers. In addition, even with electronic procurement at work, the benefits of inter-firm cooperation are subject to learning curve effects and in order to fully benefit from the introduction of a new application, both parties need time to comprehend and adapt to the new organization of activities (Clemons et al. (1995)). Similarly, because the coordination cost decreases over time, firms can take advantage from transaction economies of scale only if cooperation is maintained over a longer period of time and sufficiently many transactions per relationship are carried out.

Despite an intensive debate, empirical evidence supporting any of the contradictory paradigms remains scarce. On the one hand, Holland and Lockett (1997) found that the process of supply chain integration is followed by a reduction in the number of suppliers. Similarly, Dai et al. (2000) concluded that firms indeed benefit from reduced coordination and search costs, but in some contexts buyers still maintain close relationships with selected suppliers and various business models continue to coexist. On the other hand, Hitt (1999) found that the use of ICT was associated with substantial decreases in vertical integration and, hence, an increase of the supplier number. In a study of a number of industries, Nepelski (2009) reported a clear move to the market as a result of electronic procurement as well. Similar results reveal the examination of the relationship between firm size and ICT investment conducted by Brynjolfsson et al. (1994) who concluded that increased ICT expenditures were correlated with decreasing firm size and an increased reliance on external sources.

However, there might be no simple answer to the question at stake. According to Morita and Nakahara (2003), the impact of electronic networks on the supplier-buyer relations depends, among others, on the type of products procured. On the one hand, electronic procurement reinforces the relationship between buyer and supplier if complex products are produced. Due to the highly specific nature of the investments in product design and other skills, the manufacturer might decide to sole source a particular component in spite of the benefits of electronic exchange channels offering it the access to alternative sourcing options. On the other hand, if standardized products are procured, electronic procurement enables manufactures to access a larger pool of potential suppliers and to process information on prices and product characteristics at a low cost. As a result, the number of suppliers from which buyers procure commodities and standardized products might increase.

Further studies found that the impact of data networks on firms and value chains might vary with other aspects as well. For example, Holland et al. (1997) analyzed five companies operating in various industries and reported that the organizations implemented inter-organizational applications to support both market and network-like forms of organizing transactions. The proportion of market and hierarchy elements was contingent on a range of market, strategy and economic variables. Similarly, Mühge (2004) concluded that as the transaction complexity and asset specificity increase, the coordination effect of ICT enforces hybrid structures and the attractiveness of markets decreases.

Apart from the price and coordination effects, the characteristics of the technology deployed to facilitate business transactions have some implications for the sourcing mode. Typically, electronic networks facilitating the interactions between a buyer and its suppliers requires some relationship-specific investments. Since these investments are not contractible, a firm has to offer its suppliers some incentives to commit some resources and ensure that once the investments have been made they will earn positive profits afterwards (Bakos et al. (1997)). One way to convince a potential supplier to undertake a necessary investment is to reduce bargaining power through limiting the number of sourcing options and/or agreeing to deal with him over a longer period of time. However, the argument of ICT-related relationship-specific investment is slowly losing its validity. Unlike investments in other capital goods, many ICT networks are not necessarily designed for a particular relationship. Hardware is usually standardized and deployable in any relationship and software protocols are gradually evolving towards open systems and modular architectures, independent of a particular industry or business relationship. This further reduces the transaction cost and leads to more market transactions.

Taking into account the above discussion, the following section formalizes the relationship between technology choice and sourcing mode and formulates hypotheses which are tested in section 4.4.

4.2.2 Conceptual model and hypotheses

Let us imagine an industry with a vertical structure where there are $N > 1$ upstream firms and one downstream firm. Upstream firms compete in quantities, i.e. Cournot competition, and each sells q_{ui} of non-differentiated input products to a downstream monopolist at price w. Downstream firm faces demand function $D(p) = 1 - p$, where $D'(p) < 0$, and sells its output at monopoly price p to final customers. For simplicity, it is assumed that all upstream firms have neither production cost nor capacity constraints. Thus, each supplier faces the following maximization problem:

$$\pi_i = wq_{ui}, \tag{4.1}$$

and the profit function of a single downstream firm is

$$\pi_d = D(p)p \tag{4.2}$$

The monopoly's production cost is equal to the input price w. Furthermore, I assume that the upstream firm has to pay $C > 0$ for each supply contract. Thus, its profit function takes the following form:

$$\pi_d = (p - w)D(p) - NC \tag{4.3}$$

where N is the number of upstream firms from which the downstream firm procures intermediate products.

The simple game has three stages. In the first stage, downstream firm chooses the number of suppliers from which it procures the intermediary product. In the second stage, upstream firms set quantities and, in the last stage, a downstream monopolistic producer sets p and sells its product to the final customers. The game is solved by backward induction. Thus, the price of the final good is obtained by maximizing (4.3) with respect to p. This yields the following FOC:

$$(p - w)D'(p) + D(p) = 0 \tag{4.4}$$

Consequently, the monopoly's price and quantities are $p = \frac{1+w}{2}$ and $D(p(w)) = \frac{1-w}{2}$. These values enter the profit functions of upstream firms, which due to Cournot competition in the upstream market, set wholesale price $w = \frac{1}{1+N}$ and quantity per firm $q_{ui} = \frac{1}{2(1+N)}$. Substituting these values into the profit function of the monopoly firm yields

$$\pi_d = \frac{N^2}{4(N+1)^2} - NC \tag{4.5}$$

Eventually, by maximizing the above function with respect to the number of suppliers gives the following expression:

$$\frac{N}{2(N+1)^3} - C = 0. \tag{4.6}$$

The above expression illustrates the trade-off between the number of suppliers and transaction costs. The first part of the equation shows how an increase in the number of suppliers positively influences firm's profit. This effects comes from an intensified competition in the upstream market. However, the cost of dealing with upstream firms negatively influences the firm's payoff. Thus, the positive effect of ICT on the cost of interacting with suppliers enables companies to use markets more efficiently, as it lowers search and evaluation costs and gives access to a larger number of potential suppliers. This leads to the following hypothesis:

> **Hypothesis 1**: A positive effect of ICT on the procurement cost creates an incentive to increase the number of suppliers.

Although ICT lowers the overall cost of transaction, the cost of procurement and thus the incentive to enlarge the supplier pool is also subject to asset specificity, product complexity and the necessity for relationship-specific investments. These factors increase the cost of coordination. To illustrate this, let us assume that the transaction cost function is of the form $C(a) > 0$, where $C'(a) > 0$ and $a > 0$ represents a parameter of product specificity and the need for relationship-specific investments. This parameter can be interpreted in the following way: if the value of a is low, then input products are of low specificity and no relationship-specific investments are required. In contrast, if the value of a is high, the degree of asset specificity is high. In particular, product complexity raises a variety of transaction costs such as the coordination cost incurred when designing a component and executing its production (Novak et al. 2001). Taking into account the amount of time and effort that has to be invested in product design, the buyer might prefer to restrict the number of suppliers or even choose sole sourcing. In other cases, the buyer has to offer suppliers some incentives to make a relationship-specific commitment. One way of encouraging such commitments is by reducing the number of alternative sources. Consequently, the procurement of relationship-specific products lowers firms' incentive to increase the number of suppliers. This leads to the following hypothesis:

> **Hypothesis 2:** Transaction specificity is negatively correlated with the number of suppliers.

The first hypothesis reflects the fact that, holding everything constant, companies are likely to increase the number of suppliers in order to benefit from upstream competition. The second hypothesis accounts for the fact that the competition benefits are offset by transaction cost increasing with the specificity of procured inputs. The net effect of the price and coordination effect determine the final decision with respect to the optimal number of sourcing options.

4.3 Data

The data used in this analysis stems from the e-Business W@tch 2006 survey (see www.ebusiness-watch.org). The main objective of the undertaking includes monitoring the adoption, development and impact of electronic business practices in different sectors of the European economy. The e-Business W@tch surveys focus on the availability and usage of ICT and the perceived importance and impact of e-business at the company level. Apart from the numerous questions relating to the usage and relevance of ICT, all data sets contain background information about each firm, e.g. sector, country of origin, number of employees, size class and number of establishments. Within the 2006 survey, over 14,000 interviews were conducted that covered firms from ten industries in 19 European countries. Table 4.3 in annex presents the definition of the sectors according to the NACE Rev. 1.1. together with the number of interviews conducted in each sector.

Despite a very comprehensive approach to the technology use and its impact, the data collected by e-Business W@tch has some limitations. In particular, the observations are based on respondents' perceptions which cannot be verified. In addition, most of the indicators are reported on limited scales such as *yes/no* or *increase/decrease/stay the same*. This considerably limits the possibilities of a thorough analysis and the choice of the empirical methods that can be used. In addition, because all interviews were conducted at one point of time, no direct causality effects can be established. Instead, as in this study, one needs to use surrogates, which are again based on the respondents' perceptions. In spite of these limitations, e-Business W@tch is an exceptional source of information on the diffusion, use and impact of ICT. In particular, the large range of questions aiming at assessing the effects of technology adoption on firm performance and behavior makes it suitable for the study of ICT and its economic implications.

Below, I describe all variables used in the study. Detailed information on the origins of the indicators can be found in annex. In particular, table 4.4 matches the variables with their counterparts in the survey questionnaire and table 4.5 gives an overview of variables' main statistics.

Dependent variable: Each respondent participating in the survey who positively answered the question whether her company uses the internet or other mediated networks to place orders for goods or services was asked how electronic procurement affected the number of suppliers. Table 4.1 presents firms' answers to this question by sectors. Irrespective of the industry, the largest share of firms did not see any change in the size of supplier pool resulting from the introduction of the new transaction channel, i.e. over two thirds of all firms. Only a small group of firms said that the deployment of electronic sourcing was followed by a decrease in the number of suppliers and, on average, 26% of all firms increased the number of suppliers after the introduction of the new procurement technology and practices.

Because ICT enables firms to bundle procurement activities in order to exploit economies of scale, most of the firms that have implemented sophisticated electronic procurement schemes have the explicit target to streamline their supplier base. A lack of the impact and the dominating move towards more markets transactions is therefore somewhat surprising. This leads to three conclusions. First, in general, the introduction of electronic procurement did not change companies' sourcing behavior. Second, in contrast to some prior predictions (e.g. Bakos et al. (1997)), a significantly larger group of firms increased the size of their supplier pool, compared to those that reduced it. Lastly, there are extensive differences between industries regarding the impact of ICT on the organization of economic activities. This suggests that due to some inter-industry differences, the impact of ICT on the organization of economic activities varies from sector to sector.

Table 4.1: The effect of e-sourcing on the number of suppliers by sector (in %)

Sector	increase	decrease	stay the same
Construction	0.24	0.05	0.70
Consumer electronics	0.34	0.04	0.62
Food and beverages	0.20	0.08	0.72
Footwear	0.23	0.05	0.71
Hospital activities	0.24	0.08	0.69
ICT manufacturing	0.28	0.05	0.66
Pulp and paper	0.22	0.05	0.73
Shipbuilding and repair	0.28	0.03	0.69
Telecommunications	0.30	0.05	0.64
Tourism	0.27	0.06	0.67
Total	0.26	0.06	0.68

Source: e-Business Watch 2006 survey data.
N=7434

To explain the relationship between the new transaction mode and its impact on the number of suppliers, in the proceeding analysis, I use a number of variables that control for the effect of ICT on transaction costs, the use of technology in the procurement process, procurement patterns and firms' characteristics. Below, I define all explanatory variables in detail.

ICT and transaction costs: As discussed in Section 4.2, the abstract nature of transaction costs makes including them in an empirical analysis quite a challenging task (Joskow (1988)). A theoretical attempt to create a model for assessing the impact of electronic procurement on purchasing costs was made by Boer et al. (2002). Empirical testing requires, however, concrete measures of market complexity and asset specificity, as well as a means to assess when and how specific investments are important. With the data at hand, it is not possible to quantify the effect of a new transaction mode on transaction costs. Thus, I use a variable that proxies the effect of ICT on the procurement cost of supply goods. This indicator is based on the answers to the question of what impact ICT had on the procurement cost of supply goods. Respondents could choose between three options: (1) increase, (2) decrease or (3) stay the same. It has to be noted, that the proxies should not be confused with the effect of electronic procurement on input prices.

According to companies' answers, (see table 4.5, annex), half of them reported no effect of electronic procurement on the cost of procurement. If there was any effect of the new transaction mode, it was rather positive. Only 3% of all firms reported a negative impact of the new technology on the procurement cost. Considering the nature of the technology, these results do surprise and are consistent with the arguments presented above.

Asset specificity: As noted in previous section, the type of products procured by companies might influence the transaction costs and, thus, the organization of vertical relations and the choice of supply options. Hence, there are five variables controlling for the following product groups that are procured online: (1) maintenance, repair and operation (MRO) goods, (2) raw materials, (3) intermediary products, (4) services and (5) all of these. This product classification serve as approximations of asset specificity, i.e. it is assumed that the MRO and raw materials are the least and intermediary products and services are the most complex to procure online. The rationale behind this assumption is that, in general, MRO goods and raw materials are often standardized and available from multiple suppliers. Consequently they are typically a starting point for online activities, as most of traders and platforms offering these types of products offer electronic product catalogues or other electronic order forms. In contrast, intermediary products and services require considerable pre-transaction effort to define technical specifications and other transaction terms of the contract. Due to these obstacles, they are purchased online less often or at a lower scale than MRO goods or raw materials. This is confirmed by the data as well. For example, on average, MRO goods and raw materials are procured online around twice as often as production inputs and services (see table 4.5, annex). This confirms the conjecture that MRO goods can be easier procured online indeed, compared to direct production products. Thus, throughout the following analysis, I assume that MRO goods and raw materials exhibit lower product specificity and are more prone to be traded online, compared to intermediary inputs and services. However, once again it has to be noted that these product groups are a very crude approximation that does not account for a number of factors. For example, in many industries and for a number of products, the quality of raw materials is critical to such a degree that they are only procured from trusted suppliers and, hence, buyers will not change their input source based only on cost arguments.

Distance to suppliers: Another variable related to the transaction cost is the origin of suppliers. Concerning the origin of the supplier base, electronic procurement is often perceived as an accelerator of international trade. Thus, a high propensity of international online purchases would be an indicator that electronic procurement eliminated barriers to international trade and reduced transaction cost for cross-border business. If true, this would give companies an incentive to increase the number of their sourcing options. This, however, could be counter-balanced by the still persisting differences in taxation and accounting rules and, in some sectors, regulation requirements.

In the survey, companies were asked whether they buy online from national or international suppliers. It can be expected, that if a large share of online transactions is conducted across borders, this might be an implication of a positive impact of ICT on transaction cost. At the same time, however, the geographical composition of electronic transactions might only reflect the pattern of supply that was present before the introduction of electronic procurement. This case is thus another example of the problem related to the causality direction, which cannot be established with the current data.

Transaction economies of scale: Although the adoption of technologies that lower searching and filtering costs increases firms' incentives to increase the number of sourcing options (Mukhopadhyay et al. 2002), firms can take advantage from such technologies only when transaction economies of scale are realized. In other words, to benefit from the introduction of a new procurement mode, firms might need to maintain cooperation over a longer period of time and carry out sufficiently many transactions per relationship. This might be a reason why firms decide not to increase the number of their suppliers or even decrease it, after the new technology and procurement practices have been implemented (Clemons et al. 1995). Thus, in order to control for the importance of the transaction economies of scale in the process of defining a firm's sourcing strategy, I use the following five dummy variables that measure the share of goods bought online in the total procurement: (1) less than 5%, (2) between 5% and 10%, (3) between 11% and 25%, (4) between 26% and 50% and (5) above 50%.

ICT in the procurement process: To cast more light on the specific use of ICT in the procurement process, four dummy variables are used. They are based on companies' answers to the questions on the use of ICT for such activities as (1) finding suppliers in the market, (2) inviting suppliers to quote prices or submit proposals, (3) ordering goods or services and (4) running online auctions. Each variable takes value 1 or 0 if a firm uses an ICT tool for the activities specified above. Due to the characteristics of these applications and practices, it can be expected that all of them increase the probability of a firm to increase its sourcing options.

Firm characteristics: In order to account for firms' characteristics, dummy variables controlling for company size and age are used. There are four size categories ((1) less than 9, (2) 10-49, (3) 50-249 and (4) above 250 employees) and four age groups (founded in one of the following periods: (1) before 1981, (2) between 1981 and '86, (3) between 1987 and '02 and (4) 2003 to '06). Based on which company size class or age group a firm belongs to, the relevant size and age dummy takes value 0 or 1.

4.4 Empirical analysis

4.4.1 Multinominal logit model

In the empirical part of the current analysis, I use a multinominal logit model of the impact of electronic procurement on the supplier number in which the dependent variable takes one of three values: (0) if the number of suppliers decreased as a result of electronic procurement, (1) if it stayed roughly the same and (2) if it increased. This approach is equivalent to estimating the utility derived from each alternative state (Amemiya (1981)). In the following, I assume also that each firm chooses the alternative sourcing strategy that maximizes its utility. The total utility is a function of independent variables specified in the previous section.

More formally, I assume that firm's i utility from a change in the number of suppliers following the introduction of a new procurement mode j, U_{ij}, $(i = 1, ..., n;\ j = 1, 2, 3)$ is a function of a firm's characteristics and a stochastic error. Thus, a possible representation of the problem at stake is:

$$U_{ij} = \alpha + \beta X_i + \epsilon_i \tag{4.7}$$

where X_i is a vector of a firm's characteristics and ϵ_i controls for unobserved effects and is assumed to be independent from the explanatory variables (Wooldridge (2003)). In the regression, I control for sector effects by including a set of industry dummy variables and want to estimate $\beta's$, i.e. variables' coefficients.

The term α represents the baseline probability of reducing or increasing the number of suppliers as a result of the decision to procure online. In the context of the previous discussion, α might represent the 'administrative burden and costs' of increasing the number of suppliers or the reduction of upstream competition when a firm decides to procure from fewer suppliers, other things equal. Thus, in both cases, α is expected to be negative.

Regarding the methodology used in this study, multinominal logit models are widely applied and well understood (see e.g. Amemiya (1981), Dow et al. (2004), Weeks (1997)). The main advantages of this type of models include the ease of estimation and the parametrization of the model characterized by a high degree of flexibility. However, multinominal logit models suffer from some limitations as well. Most notably, they rely on relatively restrictive error distribution assumptions. Consequently, the models exhibit a problem commonly known as "independence of irrelevant alternatives" problem. Furthermore, the values of the coefficients are difficult to interpret. Thus, in order to check the robustness of the empirical findings, I conducted an analysis based on a multinominal probit model. Because the alternative specification did not yield any qualitatively different results, in the next section, I report the results of the multinominal logit estimation.

4.4.2 Results

Table 4.2 presents the regression results of the multinominal logit estimates for the impact of electronic procurement on the number of suppliers. In both cases, the model performs better than an empty model, i.e. without any variables. Further, it should be noted that the constant terms have a negative effect on the probability of electronic procurement leading to an increase or decrease in the number of suppliers. This casts some light on the general approach towards procurement strategy and, given the specification of the model, can be interpreted as an indirect measure of the administrative burden companies incur by increasing the number of suppliers, or the forsaken benefits of upstream competition in case of the reduction of the supplier number. Thus, the negative values of the constant term for both specifications is consistent with the previous expectations. The remaining coefficients provides an estimate of its impact on the dependent variable relative to this baseline.

Regarding the effect of ICT on the cost of procurement, it can be seen that it is equally important for an increase and decrease of the supplier number. Consistently with the theoretical predictions in section 4.2, positive effect of ICT on transaction cost increases the likelihood of a firm increasing the number of its sourcing option. The reverse can be observed when ICT lead to an increase of the procurement costs. Paradoxically, however, the positive impact of ICT on the cost of procurement can increase the chances of decreasing the number of suppliers as well. This new finding provides evidence that lower transaction cost might not immediately lead to more market transactions and, instead, companies might concentrate on a close cooperation with fewer suppliers. An explanation of this phenomenon can be found, for example, in Clemons et al. (1995) or Thompson (2004). They argue that firms decide not to increase the number of their suppliers or even decrease it after the new technology and procurement practices have been implemented. According to them, companies that implement inter-organizational systems and new procurement technologies benefit from reduced costs of information exchange and processing, but they do not immediately switch to markets in order to intensify competition between suppliers. Instead, such firms create networks in which suppliers and buyers form closed business relationships facilitated by ICT. Such behavior is most likely when products are characterized by a high degree of complexity or when mutual investments are required.

An analysis of the coefficient values of the variables controlling for the use of ICT tools in the procurement process shows that out of four different variables two increase the likelihood of electronic procurement having a positive impact on the number of suppliers. This allows to conclude that one of the channels through which ICT allows firms to increase the number of their sourcing options is the lower cost of searching and selecting new suppliers. As indicated by the positive coefficient value of the variable controlling for online procurement from international suppliers, the source of new suppliers can lie outside of the buyer's country. This allows for a conclusion that electronic procurement might eliminate the barriers to the cross-border trade and gives firms access to potential suppliers.

Regarding the share of online transactions in total procurement, there results are not conclusive. In general, the more a firm procures through electronic networks, the more likely it is to change the number of its suppliers. The direction, however, is not clear. This finding combined with the effect of ICT on the procurement cost confirms that the effect of electronic procurement on firms' sourcing strategies is not homogeneous.

The effect of asset specificity on the supplier choice is unclear as well. Only one coefficient is significant, i.e. the one controlling for procurement of raw materials decreases the likelihood of a firm increasing the number of suppliers. The lack of effect of the type of products ordered online on the dependent variable can be attributed to the imperfection of the proxies for the input complexity.

Turning to the variables controlling for firms' characteristics, the change in the number of suppliers varies with respect to firm size and age. Whereas small and young firms are more likely to increase the number of suppliers, their larger and older counterparts are more prone to reduce it. This puzzling finding can be explained by using the risk-augmented transaction cost perspective presented by Kauffman and Mohtadi (2004). In their analysis, they distinguish between three types of electronic procurement methods, i.e. proprietary, open and hybrid platforms, and argue that each of them has different implications for transaction cost and information uncertainty. Whereas open systems offer the lowest transactions cost, they are associated with the highest information uncertainty and supply risk. The reverse is true for closed systems. In their framework, firm size and uncertainty are the source of the inability to correctly predict final demand and actual supply. As a result, on the one hand, larger firms are more likely to adopt costlier solutions, which offer them more certain-to-deliver value and, on the other hand, smaller firms tend to choose applications, i.e. open platforms, that minimize transaction costs, but whose use entails greater supply uncertainties. This interpretation is additionally reinforced by the finding that the positive impact of ICT on the cost of procurement is positively correlated with a firm increasing the number of suppliers and that the negative impact of ICT on the cost of procurement is more likely to be followed by a decrease in the sourcing options.

4.5 Conclusions

The preceding analysis sought an answer to the question of how electronic procurement affects the number of suppliers. Two observations motivated the

Table 4.2: Multinominal logit estimates: the impact of e-procurement on the number of suppliers

		Increased/stayed the same		Decreased/stayed the same	
		Coefficient	Standard error	Coefficient	Standard error
ICT impact on procurement cost	positive	0.693***	0.06	0.555***	0.11
	negative	0.223	0.20	0.734**	0.29
Use IT to look for suppliers		0.668***	0.14	0.135	0.23
Use IT to invite suppliers to quote prices		0.319**	0.15	0.161	0.26
Use IT to order goods or services		-0.137	0.14	0.286	0.24
Use IT run online auctions		0.181	0.16	-0.328	0.32
Buy online from international suppliers		0.333***	0.07	-0.166	0.14
Share of online orders	5 to 10	0.314***	0.09	0.308*	0.17
	11 to 25	0.608***	0.09	0.670***	0.17
	26 to 50	0.607***	0.09	0.793***	0.17
	>50	0.588***	0.08	1.140***	0.15
Types of orders	MRO	0.052	0.08	-0.043	0.15
	Raw materials	-0.125*	0.08	-0.033	0.14
	Intermediary inputs	-0.011	0.11	-0.271	0.22
	Services	0.130	0.09	0.016	0.18
Number of employees	10 to 49	-0.137**	0.07	0.007	0.14
	50 to 249	-0.196**	0.08	0.450***	0.14
	>250	-0.208	0.15	0.936***	0.21
Year of foundation	1981 to '86	0.006	0.08	-0.486***	0.13
	1987 to '02	0.131	0.09	-0.462**	0.15
	2003 to '06	0.193*	0.11	-0.688**	0.22
Intercept		-1.994	0.13	-2.856	0.21

Log likelihood = -5413.097
LR chi2(60) = 692.24
Prob > chi2 = 0.000
Pseudo R2 = 0.06

Estimation uses e-Business Watch 2006 survey data.
N=7431
Reference categories: firms reporting no influence of e-procurement on the procurement cost of supply goods, procuring online from national suppliers, procuring online less than 5% of total procurement, procuring online all types of goods, with <9 employees, founded before 1981 and operating in the food and beverage industry.
Signifficance level: * = 10%, ** = 5%, *** = 1%.

current analysis. First, there are contradicting predictions with respect to the impact of ICT on firms' sourcing strategies in general and the choice of the number of sourcing options in particular (see, e.g., Malone et al. (1987) and Clemons (1993)). Second, there is a lack of empirical evidence that would support any of the way of thinking about the way electronic procurement influences the number of suppliers. By using a unique data set that combines information on the technology use and its impact, I show that there is no single answer to the question at stake and that both regimes, i.e. move to the market and move to the middle, coexist. What is more, however, most of the firms covered by the survey did not see any effect of the introduction of the electronic procurement on the number of their suppliers. If there was any, it was positive, i.e. depending on the industry, at least one out of five companies that procure goods online increased the number of their suppliers, only around 6% of all firms covered in the sample reduced the size of their supplier pool as a result of the new procurement technology and processes.

The current analysis explains the prevailing move to the market by the direct reduction of transaction cost and an indirect increase in upstream competition spurred by ICT. However, lower transaction cost does not explain the coexistence of different behavior with respect to the size of the supplier pool. It seems that firm's structural characteristics play a significant part in what effect ICT has on their sourcing strategies. For example, whereas relatively small and young companies report a positive impact of electronic procurement on the number of supplier, their larger and older counterparts seem to follow a different strategy. This indicates that the impact of ICT on relationships with suppliers and customers is not alike for every company.

To explain this phenomenon, it is useful to take into account how supply uncertainty and risk relate to different procurement technologies and, consequently, to firms sourcing strategies. For example, by acknowledging the fact that procurement systems are not alike, Kauffman and Mohtadi (2004) argue that they have different implications for transaction cost and supply risk as well. Consequently, depending on their cost and risk preferences companies might choose different procurement technology together with sourcing strategy. As a result, because firm size and uncertainty are the source of the inability to correctly predict final demand and actual supply, large firms are more likely to adopt costlier solutions and fewer suppliers. By doing so, they increase the certain-to-deliver value. At the same time, smaller and cost-oriented firms choose open applications that offer them more sourcing options and, hence, lower transaction costs, but whose use entails greater supply uncertainties.

The above results confirm the intuitive expectation that when facing different economic conditions and structural characteristics, companies adopt ICT tools for different strategic reasons that, in turn, have different implications. An immediate inference is that any further research aiming at identifying the impact of ICT on the organization of economic activities should concentrate on comparable groups of firms, operating in homogeneous economic environments. Furthermore, in the research on the impacts of ICT there is a need to account for different characteristics of various technologies and the very context in which they are applied in order to obtain a complete picture of the ICT impact on firm boundaries and organization of economic activities. Consequently, the study offers some interesting insights contributing to the debate on the impact of ICT on firm boundaries and the organization of economic activity. In particular, the investigation is limited to an analysis of one particular ICT applications, i.e. electronic procurement, and it uses indicators that focus only on this technology and its impact on selected issues. This contrasts a number of other empirical studies that aim at assessing the effect of technology on sourcing strategy or vertical relations between firms and, as a result, provides novel results with respect to the impact of electronic procurement on sourcing strategy and the organization of vertical relations in supply chain.

Despite delivering some novel insights, the study suffers from some limitations. In particular, the variables merely mirror the perceptions of the respondents and cannot be verified. Relying on 'personal' judgements of the respondents, raises the question of the credibility of the answers and the subjectivity of the expressed views makes it difficult to define exactly what influenced what. Furthermore, the imperfections of the measure used in the study lead to strict assumptions with respect, for example, to the measurement of transaction cost or the level of product complexity and the type of goods that companies procure online. Unfortunately, these constraints do not apply only to this study. Such abstract concepts as transaction cost, asset specificity or relationship-specific investments are very difficult to define and, what is more, to measure. Consequently, the type of empirical data and approach taken in this study can be one of only few ways to study the problems similar to the one analyzed in the current work.

4.6 Annex

Table 4.3: Population coverage of the e-Business Watch 2006 survey

NACE Rev. 1.1	Sectors covered	No. of enterprises in EU25*	No. of interviews conducted
DA 15 (most groups)	Food and beverages	282,000	1,701
DC 19.3	Footwear	13,700	978
DE 21	Pulp, paper and paper products	18,400	1,158
DL 30, 32.1+2	ICT manufacturing	31,800	1,687
DL 32.3	Consumer electronics	5,400	665
DM 35.11	Shipbuilding and repair	7,200	143
F 45.2+3	Construction	1,546,000	2,654
H 55.1/3, I 63.3, O 92.33/52	Tourism	1,500,000	2,665
I 64.2	Telecommunication services	12,900	1,580
N 85.11	Hospital activities	13,000 (e)	834
Total			14,065

* mostly based on Eurostat SBS, latest available figures
(e) = estimated on the basis of figures for the former EU-15 (no figures available for EU-25)

Table 4.4: Variables and survey questions and answers

Variable	Question	Answer
Impact of e-sourcing on the number of suppliers	What effect did your online ordering and e-sourcing activities have on the selection of suppliers? Would you say the number of different suppliers has increased, decreased or has it roughly stayed the same?	(1) increased (2) decreased (3) roughly stayed the same (4) DK
ICT impact on procurement cost	All in all, in what ways have information and communication technologies influenced the business of your company? Please tell us for the following areas whether ICT have had a positive influence, a negative influence, or no influence at all. What was the influence of ICT on … (d) procurement cost of supply goods	FOR EACH: (1) positive (2) negative (3) no influence (4) DK
Use IT for…	And which of the following sourcing or procurement related processes does your company support by specific IT solutions? Do you use IT solutions for…? (a) Finding suppliers in the market (b) Inviting suppliers to quote prices or submit proposals (c) Ordering goods or services (d) Running online auctions	FOR EACH: (1) yes (2) no (3) DK
Buy from international suppliers	Are online orders MAINLY from regional, [country] or international suppliers?	(1) regional suppliers (2) [country] suppliers (3) international suppliers (4) DK
Share of online orders	Please estimate how large a share of the total volume of your orders is placed ONLINE. Would you say …	(1) more than 50% (2) 26 up to 50% (3) 11 up to 25% (4) 5 up to 10% (5) less than 5% (6) DK
Types of orders	Do your online orders MAINLY concern MRO goods, raw materials, intermediary products, services or rather all of these?	(1) MRO goods (2) raw materials (3) intermediary products (4) services (5) all of these (6) DK
Number of employees	Would you be able to tell me to which of the following size groups your company belongs?	(1) 1 - 9 employees (2) 10-49 employees (3) 50 - 249 employees (4) 250+ employees (5) DK / no answer
Year of foundation	Was it more than ten years ago, ten to three years ago, less than three years ago?	(1) More than 25 years ago (2) Between 11 and 25 years ago (3) Between 10 and 3 years ago (4) Less than 3 years ago (5) DK/ no answer
Questionnaire and methodology report available at: http://ebusiness-watch.org/about/documents/eBiz_Questionnaire_2006.xls http://ebusiness-watch.org/about/documents/DMS2006_Methodology.pdf		

Table 4.5: Descriptive statistics

Variable		Mean	Standard deviation
Effect of e-procurement on the number of suppliers	increase	0.14	0.34
	decrease	0.03	0.17
	stay the same	0.36	0.48
ICT impact on procurement cost	positive	0.41	0.49
	negative	0.03	0.16
	no impact	0.51	0.50
Use IT to look for suppliers		0.08	0.27
Use IT to invite suppliers to quote prices		0.08	0.28
Use IT to order goods or services		0.10	0.30
Use IT run online auctions		0.02	0.14
Buy online from international suppliers		0.11	0.31
Share of online orders	<5	0.16	0.37
	5 to 10	0.11	0.31
	11 to 25	0.08	0.28
	26 to 50	0.08	0.27
	>50	0.12	0.32
Types of orders	MRO	0.11	0.31
	Raw materials	0.13	0.34
	Intermediary products	0.05	0.21
	Services	0.07	0.25
	All of these	0.20	0.40
Number of employees	1 to 9	0.38	0.49
	10 to 49	0.26	0.44
	50 to 249	0.18	0.38
	50 to 249	0.05	0.21
Year of foundation	before 1981	0.26	0.44
	1981 to '86	0.42	0.49
	1987 to '02	0.22	0.42
	2003 to '06	0.09	0.29

Source: e-Business Watch 2006 survey data.
N=14,065

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Ich bezeuge durch meine Unterschrift, dass meine Angaben über die bei der Abfassung meiner Dissertation benutzten Hilfsmittel, über die mir zuteil gewordene Hilfe sowie über frühere Begutachtungen meiner Dissertation in jeder Hinsicht der Wahrheit entsprechen.